DISTRIBUTED AMPLIFIER TUBES

Report No. 19

Final Report
1 May 1962 through 30 July 1963

Contract No. DA 36-039 sc-90743
(Continuation of Contract DA 36-039 sc-75070)
DA Project No. 1G6-22001-A-055

U. S. Army Electronics Research & Development Laboratory
Fort Monmouth, New Jersey

Power Tube Department
General Electric Company
Schenectady, New York 12305

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Technical Requirements No. SCL-7001/67, dated 14 August 1961

DA Project No. 1G6-22001-A-055

Objective: To develop and construct a distributed amplifier tube capable of delivering a minimum power output of 200 watts and operable over a frequency band from 6 to 600 megacycles.

C. B. Mayer

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PURPOSE

This contract was initiated to develop a tube for use in a distributed amplifier to meet the objective specifications given in Signal Corps Technical Requirements No. SCL-7001/67 dated August 14, 1961. The work performed on this project was a continuation of work accomplished under Contract No. DA 36-039 sc-75070, dated April 25, 1958.

The purpose of the program was to investigate the factors which would lead to an improvement of the distributed amplifier tube, as developed under Contract No. DA 36-039 sc-75070, so as to increase the minimum power output from 100 watts to 200 watts and the minimum frequency bandwidth from 6-500 MC to 6-600 MC. Ir developing the tube with such improvements, the construction advantages inherent in the single-tube, dual-sided design, and the size and weight of the tube as developed under Contract No. DA 36-039 sc-75070 were to be retained.

ABSTRACT

This report describes the continuation of the research work conducted under Contract No. DA 36-039 sc-75070 on a single tube distibuted amplifier. The problems encountered and the solutions obtained which led to the present performance are described.

The major improvements which have been made in the tube are:

1) Increased anode dissipation capability
2) Increased screen-grid dissipation capability and stability
3) Improved emission

These improvements, along with circuitry studies and modifications, have led to improvements in frequency bandwidth, power output, and power gain.

The best performance which has been obtained to date is given in Table I. The ultimate performance of the present design has not been determined.

Table I

Frequency (MC)	Power Output (watts)	Drive Power (watts)	Power Gain (db)	Plate Voltage (volts)	Plate Current (amperes)	Efficiency (%)
<300	≥ 170	3.8	≥ 16.5	330	≈ 3.3	≥ 15.6
300	170	3.8	16.5	330	≈ 3.3	15.6
400	153	3.8	16.0	330	≈ 3.3	14.0
475	140	3.8	15.7	330	≈ 3.3	12.8
600	102	3.8	14.3	330	≈ 3.3	9.3

PUBLICATIONS, LECTURES, REPORTS, AND CONFERENCES

PUBLICATIONS - None

LECTURES - None

REPORTS

1. Report No. 15, First Quarterly Progress Report, Distributed Amplifier Tubes, by C. B. Mayer, Power Tube Department, General Electric Company, for the period from May 1, 1962 through July 31, 1962.

2. Report No. 16, Second Quarterly Progress Report, Distributed Amplifier Tubes, by C. B. Mayer, Power Tube Department, General Electric Company, for the period from August 1, 1962 through October 31, 1962.

3. Report No. 17, Third Quarterly Progress Report, Distributed Amplifier Tubes, by C. B. Mayer, Power Tube Department, General Electric Company, for the period from November 1, 1962 through January 31, 1963.

4. Report No. 18, Fourth Quarterly Progress Report, Distributed Amplifier Tubes, by C. B. Mayer, Power Tube Department, General Electric Company, for the period from February 1, 1963 through April 30, 1963.

CONFERENCES

1. On September 25 and 26, 1962, Mr. M. M. Chrepta of the USAELRDL, Fort Monmouth, N. J. visited Messrs. C. B. Mayer, R. P. Watson, and R. H. Mack of the General Electric Power Tube Department at Schenectady, N. Y. to discuss progress on this contract.

2. On January 16, 1963, Mr. M. M. Chrepta of the USAELRDL, Fort Monmouth, N. J. visited Messrs. C. B. Mayer, R. P. Watson, and R. H. Mack of the General Electric Power Tube Department at Schenectady, N. Y. to discuss progress on this contract.

3. On February 20, 1963, Messrs. C. B. Mayer, R. H. Mack, E. Craig, and H. Tate of the General Electric Power Tube Department met with Messrs. D. Ricker, M. Zinn, G. Taylor, M. Chrepta, B. Louis, and C. Norton of USAELRDL at Fort Monmouth, N. J. to (1) discuss progress on the contract, (2) consider new ideas for improved distributed amplifier efficiency, and (3) review the system requirements of the device. It was concluded that the device could be utilized in the systems application for which it was intended if a power output of 100 watts were obtained over the band at a gain of 12-15 db. Also, future technical efforts on the program should be conducted in a manner insuring the greatest probability of achieving these objectives, so that a working model could be delivered to USAELRDL for systems evaluation at the end of the contract.

4. On May 1, 1963, Mr. M. M. Chrepta of the USAELRDL, Fort Monmouth, N. J. visited Messrs. C. B. Mayer, R. P. Watson, and R. H. Mack to discuss progress on the contract.

FACTUAL DATA

INTRODUCTION

This is the final report on USAELRDL Contract No. DA 36-039 sc-90743, dated May 31, 1962, which was initiated to conduct research work on distributed amplifier tubes in accordance with Signal Corps Technical Requirements No. SCL-7001/67 dated August 14, 1961 and General Electric Company, Power Tube Department letter dated March 8, 1962. The research effort on this program was to be based upon an understanding of the distributed amplifier device obtained from nearly four years of experience on distributed amplifier tubes under Signal Corps Contract No. DA 36-039 sc-75070. The work under that contract led to the development and demonstration of a single-tube distributed amplifier device with sufficient performance to dictate additional studies and development. (The device so developed was designated as the General Electric Developmental Type Z-5278 Distributed Amplifier.)

Work on this contract was initiated on May 1, 1962 and progress from that date through July 31, 1963 is reported herein. However, first, the status of the development of the Z-5278 distributed amplifier at the beginning of this program is discussed in detail.

SUMMARY OF Z-5278 DESIGN STATUS AT START OF CONTRACT

1. Tube Description

At the beginning of this program, the Z-5278 device consisted of two complete distributed amplifiers inside a single vacuum evelope. Each of these amplifiers was completely independent electrically and could be interconnected to each other or to other stages in a variety of ways to optimize performance with regard to a particular requirement, such as gain, power output, efficiency, or minimum harmonic output content. A photograph of the device illustrating the over-all appearance of the tube and its connectors is shown in Figure 1. The over-all size of the tube was approximately 4-1/2 inches by 4-1/2 inches by 7 inches. The weight of the device was approximately seven pounds.

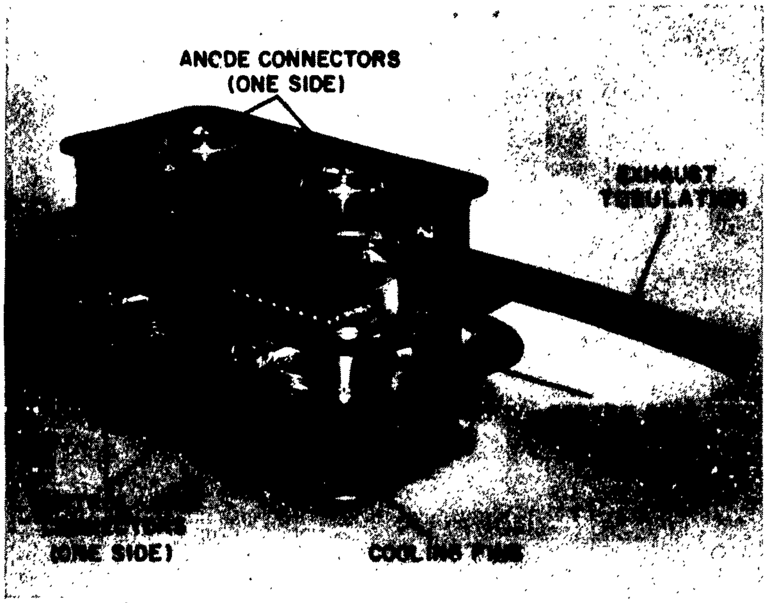


Figure 1 - Over-all View of Z-5278 Distributed Amplifier Developed During Contract No. DA 36-039 sc-75070

2. Electrical Performance

While excellent performance (150 watts output with two watts of drive) had been demonstrated at low frequencies (70 MC), the power output at 500 MC was only 24 watts with 3.4 watts of drive. Measurements and theory[1*] had indicated that active circuit loading of the input transmission line caused the degradation in performance of high frequencies. Furthermore, cold circuit studies had demonstrated a means of not only eliminating this loading but of actually making the loading ngative, whereby it could be utilized to compensate for other losses in the input line (i.e., transit time) at high frequencies. Mechanical tube difficulties prevented the demonstration of this effect in an active tube under the original contract (DA 36-039 sc-75070), however.

3. Mechanical Design

While the mechanical design of the Z-5278 which had evolved by the end of Contract DA 36-039 sc-75070 was adequate to demonstrate

*See Appendix I for references.

the electrical performance, several design limitations were uncovered which required study and modifications.

Grid-cathode shorting problems had been encountered when the heater current was raised above a given level. The cause of this problem had been ascertained by bell jar observations and a modification in the design had been made to correct the situation but had not been demonstrated in an actual tube.[2]

It had been observed that some of the thin copper anode plates tore away from the anode ceramic when anode dissipation levels in excess of several hundred watts were obtained. This problem required a solution so that reliable high power performance could be achieved.

TUBE DESIGN INVESTIGATIONS

To achieve the specifications required by this program, the active circuit loading problem had to be eliminated and the tube performance had to be improved so that 200 watts of output could be obtained with only two watts of drive for frequencies up to 600 MC. The successful achievement of these performance goals would depend largely upon improvements obtainable in screen-grid dissipation capabilities as well as the degree of improvement obtained in frequency response when grid line losses are compensated for at high frequencies by means of active circuit regeneration.

1. Grid-Cathode Shorting

As indicated in the previous section, shorting of the control-grid wires had been encountered. This shorting was caused by bending of the control-grid ceramic as a result of the heat flow through the ceramics from the cathode to the tube body. The ceramic bending resulted in an uneven tensioning of the control-grid wires which in turn loosened the wires near the middle of the grid when the heater current exceeded 15 amperes.

The shorting problem was solved by redesigning the grid structure so that the copper cooling straps were brazed to the inner edge of the control-grid ceramic (rather than to the outer edge of the control-grid ceramic as done previously). Thus, the heat flow through the control-grid ceramic was eliminated. The redesigned grid structure is shown in Figure 2. No shorts occurred between the grid terminal and

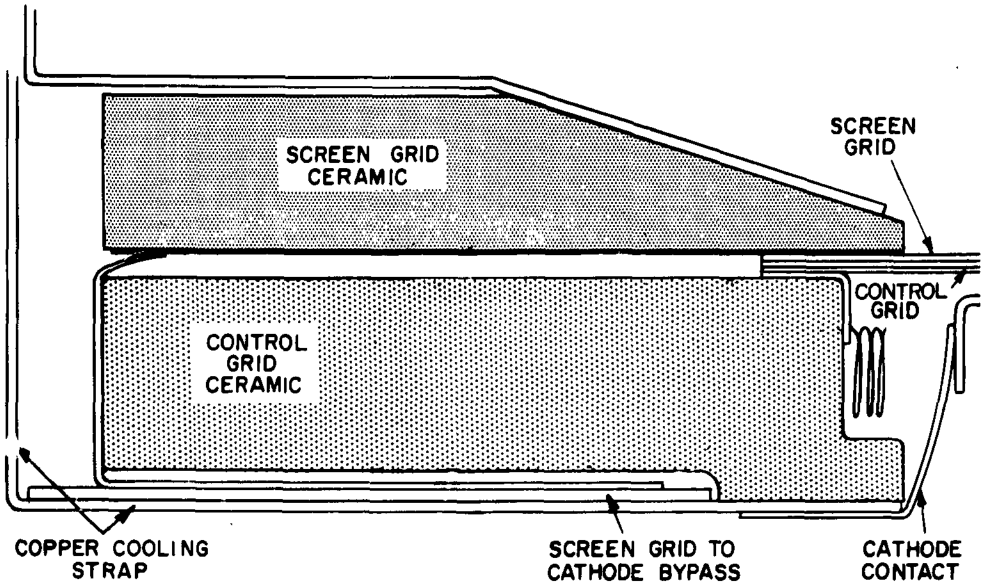


Figure 2 - Redesigned Control-Grid Structure

the body of the tube (cathode) which were attributable to loose grid wires since this modification was incorporated into the grid design. Occasional shorting difficulties have occurred which generally were attributable to the connector which forms the section of the input transmission line between the coaxial input vacuum seal and the grid to the tube. Improved methods of fabricating this connection would be desirable so that possible additional shorting problems in this area would be eliminated.

In the final tubes constructed during this program, two cross wires were brazed to the control-grid wire to increase the stability of the grid, thereby reducing any microphonic problems. The technique of brazing these wires to the control-grid wire is the same as for the screen grid and is described under "Screen-Grid Design."

2. Anode Dissipation

During assembly of the last distributed amplifier tube constructed under Contract No. DA 36-039 sc-75070, the copper anode plates tore away from the beryllia ceramic. Since several tube assemblies were available at the end of Contract No. DA 36-039 sc-75070, these assemblies were utilized to study this problem as well as to demonstrate the feasibility of transit time loading compensation.

Two of the tube bodies available for use on this program (DA 36-039 sc-90743) contained thinner copper anode plates (0.005 inch instead of 0.010 inch) than those used on the final tube of the previous contract. One tube body was assembled using two thermocouples on the anode ceramic (one at the end, the other near the middle) to measure the anode temperature. The control-grid connectors were used for the thermocouples and the control grid was tied to the cathode potential. Temperature measurements were obtained up to 450 watts dissipation for one-half of the tube, but the data were quite erratic above 300 watts because oscillations occurred in the tube.

When the tube was opened, no signs of anode plate tearing were observed and it was decided to construct an rf tube using the other tube body, which also contained 0.005-inch thick copper anode plates. The grids were removed entirely from the tube containing the thermocouples and the tube was reassembled as a diode. What appeared to be reliable data was obtained up to about 550 watts, indicating a temperature rise in the order of 180°C. Above this point, the data became erratic and it was found that appreciable leakage occurred in the tube between the thermocouples and the other electrodes, making additional temperature measurements impossible. The tube dissipation was run up to one kilowatt, however, to see what would happen to the anode plates. When the tube was opened again, it was found that all of the anode plates had torn away and several showed considerable signs of melting.

Close examination indicated also that the ceramic-to-metal seal located between the beryllia ceramic and the tube body was fracturing near the ends (thus interrupting the heat flow) and that the ceramic was cracked at the slots between the anode plates in the same direction as that of the heat flow. Evidence that this had occurred to some degree immediately after the brazing operation was obtained when another unused anode assembly was examined microscopically. Thus, it became evident that some modification would have to be made both in the means of connecting the beryllia ceramic to the tube body as well as in the anode plates.

One solution suggested for the anode plate problem was the substitution of molybdenum plates for the copper ones. While molybdenum does not match the thermal expansion of beryllia and is much stronger than copper, its expansion is much closer to beryllia than is copper and its expansion coefficient is lower than ceramic. These facts should tend to prevent the tearing away at the edges of the seal. Anode structures were fabricated from molybdenum plates using both copper

and gold solders. While the gold brazed parts yielded a much stronger bond (probably because of the greater solubility of the gold in the metalizing), voids were found continually under the gold brazed molybdenum plates in spite of several techniques which were tried to prevent such voids. Adequate bonding was obtained with the copper brazed plates when a nickel plating was applied first to the metalizing.

The problem of ceramic-metal seal fracturing between the anode ceramics and the tube body was solved by segmenting the copper brazing clamp and backing up the copper-to-ceramic joint with a strip of molybdenum.

Two new anode structures were fabricated using the molybdenum plates and segmented copper brazing clamp; and a double-sided diode was constructed to evaluate the structure. This diode was operated to a power dissipation in excess of two kilowatts; one side of the tube was operated as high as 1.3 kilowatts.

No attempt was made to provide rf loading to the diode. Evidence of possible oscillations was observed at power dissipations of approximately one kilowatt, as indicated by a departure from a smooth 3/2 power current voltage relationship (the current increased by about 10 percent above the anticipated value). Additional evidence was apparent when the tube was opened. It was observed that parts of the gold-plated molybdenum coils (which form the anode delay line) not in contact with the beryllia ceramic had been operating at a temperature sufficient to evaporate some of the gold plating. The tube actually failed when a crack occurred in the rf output seal, providing more evidence pointing to the probable presence of (unloaded) rf power in the tube.

Aside from evaporation of the gold from the coils, examination of the anode structure showed no evidence of the anode plates tearing away from the beryllia ceramic or of a fracture in the bond between the beryllia and the copper tube body. This indicated that the revamped structural design was satisfactory from a mechanical standpoint up to and probably in excess of one kilowatt.

3. Cathode Base Metal System

Until this contract, the cathode base metal system consisted of a porous coating of carbonyl nickel and titanium impregnated and sprayed with a standard triple carbonate powder. The nickel-titanium coating was sintered to a molybdenum base which formed the structural

portion of the cathode. Two problems had been experienced with the use of titanium as the activator: (1) in order to obtain good adherence between the nickel-titanium coating (which is applied by screening techniques) and the molybdenum, the nickel and titanium hydride powders must be sintered in a very good vacuum with a critically controlled temperature; and (2) excessive sublimation was experienced on some of the tubes fabricated during the previous contract. Therefore, it was decided to evaluate the use of tungsten powder as the activator in the cathode base metal system when better adherence to the molybdenum was demonstrated on several test samples. (These samples were fired in hydrogen.) It was also felt that the use of tungsten might provide less sublimation.

Thus, the dual-sided diode, which had been used to evaluate the anode dissipation capabilities of the tube, contained one cathode with a titanium activator and the other with a four percent tungsten activator. Comparison of the emission from the two halves of the tube indicated that, for this usage, the tungsten activator was at least as good as the titanium as an activator material. No definite conclusions could be drawn about the relative sublimation rates of the two systems since the tube did not operate for a sufficient length of time. Visual observations of sublimation deposits on the anodes of the tube did seem to indicate that the two systems were probably comparable in this regard.

Because of these favorable results, the next rf tube (Tube E) constructed contained two tungsten activated cathodes. Initial results on this tube were very encouraging when, after 100 hours, a DC emission of two amperes could be drawn at zero bias and relatively low screen voltage (95 volts). Considerable loss of emission occurred after the higher level operation when the overload kicked out. (It was found later that this poisoning resulted from failure of the crowbar circuit in the anode supply circuit.) It was observed that reactivation of the cathode occurred only at a very slow rate. Rough calculations which were made indicated that most of the tungsten activator may have been used up and insufficient tungsten remained to reactivate the cathode. Subsequent tubes were constructed using 20 percent tungsten powder as the activator, and reasonably good results were obtained.

4. Screen-Grid Design

The increased gain and power output objectives (200 watts output, two watts drive) for this contract over previous objectives (100 watts output, four watts drive) required that the g_m of the tube be

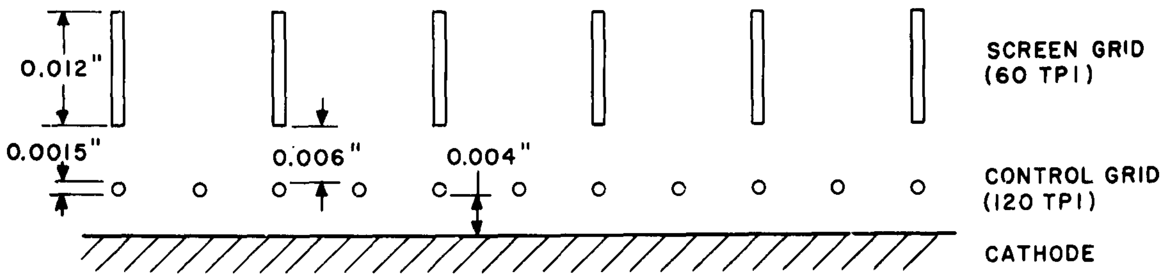
increased. In order to accomplish this, the grid-cathode spacing would have to be reduced somewhat. This reduction in grid-cathode spacing dictated a higher turns per inch (TPI) control grid which, in turn, would increase the screen grid μ and consequently the screen grid operating voltage. This increased screen voltage along with the required current increase to obtain the 200 watts output dictated the achievement of considerable improvements in the screen-grid dissipation capability of the tube.

a. Ribbon Screen Grid

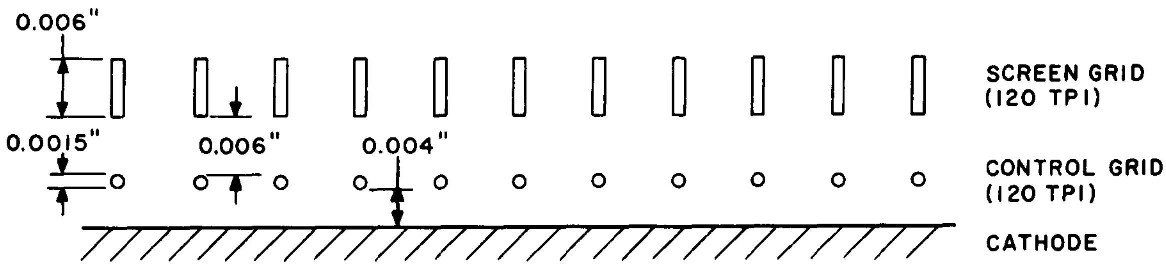
It was believed that the required improvement in screen-grid dissipation capability could be achieved by using a ribbon screen-grid structure of the type shown in either Figure 3a or 3b. Such a grid, it was felt, would provide: (1) great rigidity in the grid-grid direction, thereby eliminating any possibility of grid-grid shorts; (2) increased cross-sectional area for heat tr .sfer to the body of the tube; and (3) little or no increase in interception over a round wire grid such as shown in Figure 3c.

Considerable effort was expended in developing a technique for winding such a grid under tension in order to fabricate grids of good uniformity. The technique devised was to utilize a ceramic comb (which would have the same thermal expansion coefficient as the screen-grid ceramic) and threaded ceramic rods. The comb held the ribbon on edge on the flat part of the mandrel, while the threaded rod kept the ribbon on edge as it went around the sides of the mandrel (allowing the ribbon to be bent on edge). Figure 4 shows an end view of this setup.

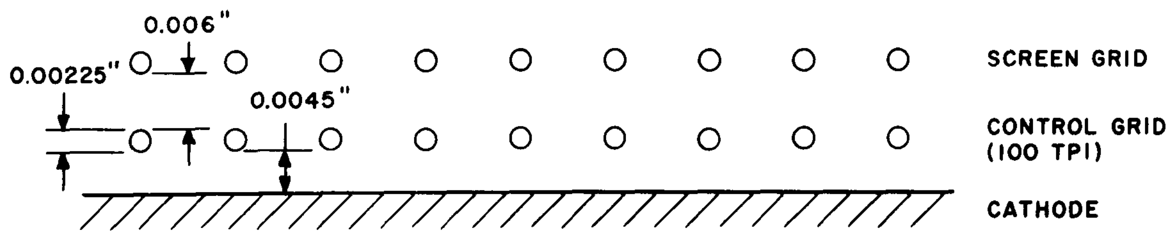
While the winding technique is fairly straight-forward, fabrication of the ceramic comb and the threaded rod is exacting. The comb and rods had to be made by cutting the teeth and thread into the ceramic in the pre-fired state and then final firing these parts. Two major difficulties were involved: (1) cutting a slot or thread 0.002 inch wide by 0.015 to 0.020 inch deep (100 TPI) in a pre-fired ceramic; and (2) obtaining the exact shrinkage during final firing so that the thread and comb will shrink to 120 TPI. The first of these difficulties was solved when a sufficiently slow feed of the cutting tool was used. The second problem was resolved by very close control over the variables involved in the final firing shrinkage. Three-inch long combs of 120 TPI were fabricated eventually with a cumulative tooth error over the entire length of approximately ± 0.001 inch.



a. Ribbon screen-grid structure with 60 TPI screen grid and 120 TPI control grid



b. Ribbon screen-grid structure with 120 TPI screen grid and 120 TPI control grid



c. Grid structure of Tube E

Figure 3 - Comparison of Ribbon and Round Wire Screen-Grid Designs

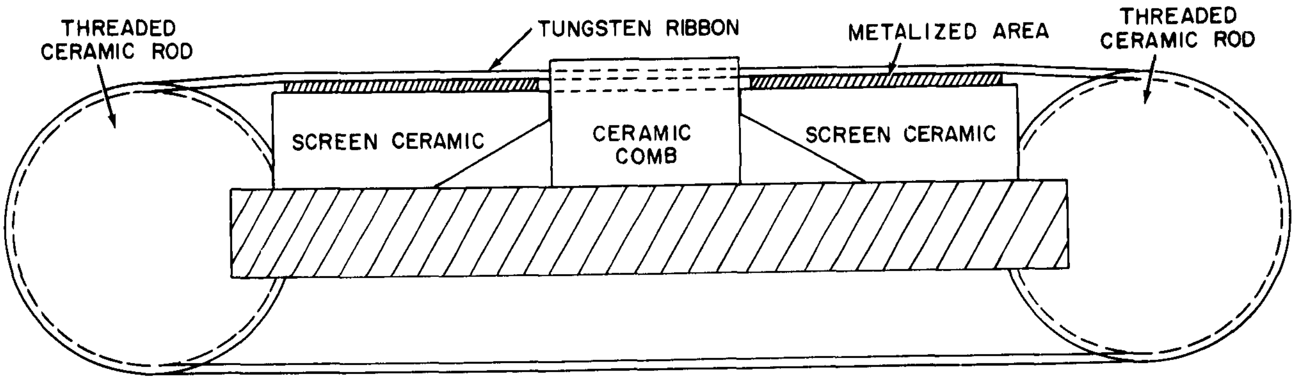


Figure 4 - Schematic Representation of Setup Used to Wind Ribbon Screen Grids (End View)

Prior to the successful fabrication of the three-inch combs, shorter sections (approximately one-inch long) of the associated threaded rods were fabricated with sufficient accuracy to demonstrate the feasibility of machine winding such a grid under tension. When considerable delay was experienced in fabricating the longer threaded ceramic rods (in order to wind a complete grid), it was decided to attempt to fabricate the grids by inserting individual grid wires (not under tension) into the comb fixture, as illustrated in Figure 5, and then brazing the grid wires to the screen-grid ceramics as depicted in Figure 6.

A number of difficulties were encountered in attempting to fabricate the grids in this manner. First, it was found difficult, on the first attempt, to braze all of the wires to the screen-grid circuit, thus requiring a subsequent rebraze. This led to nonuniformity in the length of the individual grid wires. Also, because of capillary action and surface tension, the wires tended to draw together in the brazing area. (This did not occur when the short section of the grid was brazed under tension.) This drawing action caused considerable misalignment of the grids, particularly at points where several of the teeth of the comb had broken off at the ends, and especially in the case of the 0.0015-inch by 0.006-inch ribbon since these wires were more easily bent in the transverse direction and since they were in closer proximity (120 TPI).

When the construction of the grid with the 0.0015-inch by 0.006-inch tungsten ribbon with 120 TPI appeared impractical, it was discontinued temporarily to await the necessary fixtures for machine winding the grids under tension.

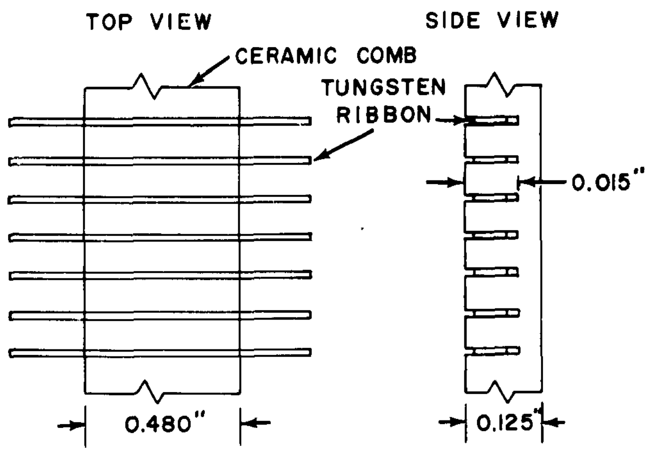


Figure 5 - Fixturing Arrangement for Construction of Ribbon Screen Grids

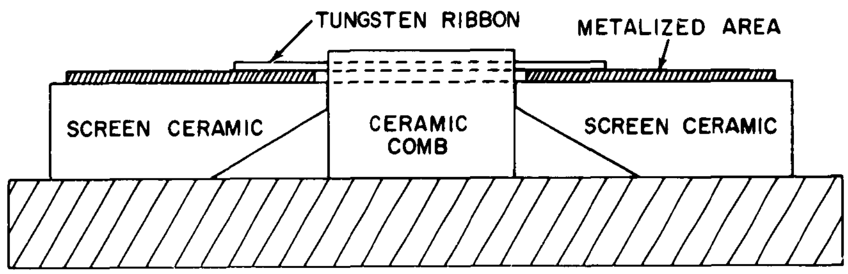


Figure 6 - Schematic Representation of Setup Used to Braze Ribbon Screen Grids (End View)

Satisfactory grids using the 0.0015-inch by 0.012-inch tungsten ribbon with 60 TPI were fabricated by this technique after making some improvement in the fixturing arrangement. While these grids were far from perfect, it was felt that they would serve to illustrate the general characteristics of this type of screen-grid structure, providing adequate tensioning could be achieved to overcome the nonuniformity in the length of the wires. This was difficult to achieve because the increased cross-sectional area of the ribbon grid structure required almost three times the total tensioning force to achieve the same stress as the 0.00225-inch diameter round wire would with 100 TPI. However, the grids appeared to have adequate tension after using a somewhat thicker screen-grid tensioning spring fabricated from Inconel 718, which has a greater high-temperature yield strength than the Inconel X material previously used.

When a hot tube was finally assembled with this type of screen grid, a 20 to 25 percent screen-current interception (in comparison to five percent for the round wire screen grid) was observed. There was, however, definite evidence that some of this current was caused by loose screen-grid wires. As the total current was increased (by reducing the control-grid bias), the screen current increased and the anode current decreased over a period of several seconds (presumably because of more wires becoming loose as they heated.) This is depicted on the curves in Figure 7 where the arrows show the direction in which the curves were traced on the x-y plotting board.

Subsequently the tube was opened and mounted in a bell jar with one of the anodes removed so that visual observation of the screen-grid wires could be made when current was drawn to them. It was noted that a considerable number of wires loosened and became misaligned when current was drawn to the screen grid. This observation verified the fact that misalignment caused some of the high screen interception, but the exact extent of the interception due to misalignment could not be ascertained.

In view of these results, a number of flux plots were made to study the problem. From these plots, it appeared that, for negative-grid operation (which is the desired operating region because of the detrimental attenuation effects of positive-grid loading), the converging lens action of the control grid may be too strong to avoid significant screen-grid interception for this type of structure. Should this be true, then the grid interception would probably be nearly proportional to the grid

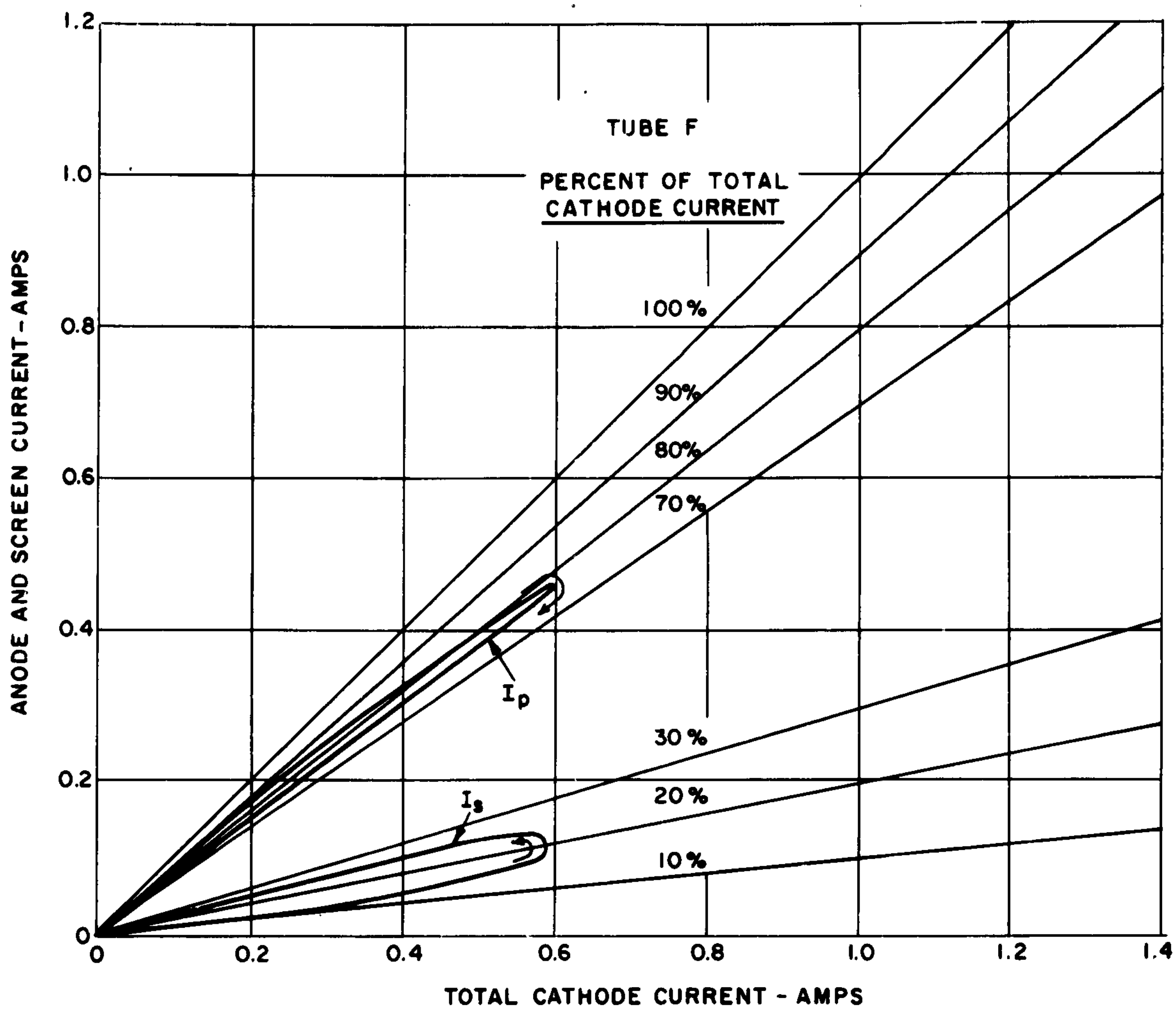


Figure 7 - Curves Showing Current Division, Tube F

depth and no improvement would be achieved by this technique. In fact, in this case, it was felt that using round wire of increased diameter might be the best means of achieving higher dissipation, since the interception would be proportional to the diameter, whereas the dissipation capability would be approximately proportional to the square of the diameter.

b. <u>Cross-Wire Grid</u>

In view of the preceding results, other means of improving the screen-grid structure were explored. It appeared that considerable improvement in grid dissipation might be achieved by using several cross wires brazed to the screen grid. Such cross wires would eliminate both the possibility of an individual wire receiving excessive dissipation and the possibility of runaway action and subsequent shorting, since all of the screen-grid wires would be tied together at several points along their span. (This technique has been very successful in increasing the control-grid dissipation capabilities in such tubes as the GL-2C39.)

An additional factor could have contributed to the instability and shorting problems experienced in the past because of screen-grid dissipation. Operation at high frequency and large signal rf conditions perturbs the dc beaming at the points along the tube where the individual tube sections are adjacent to each other. Under these conditions, an rf voltage exists between adjacent tube sections and, hence, between the two control-grid wires at the ends of each section. This rf voltage steers the electron steam back and forth causing additional screen-grid interception on the two screen-grid wires directly behind these control-grid wires. The use of the cross wires would prevent these wires from shorting. Also, the actual removal of the cathode coating at these points would be desirable in order to further reduce this effect.

Therefore, it was decided that, although the ribbon screen grid might still have merit (assuming that loose wires caused much of the observed interception on the ribbon screen-grid tube), adequate performance for system requirements could be met if a compromise were made in gain and power output. In this case, a round wire grid structure could be utilized if means of improving the grid stability could be obtained by brazing cross wires to each screen-grid tube section and removing the cathode coating between adjacent tube sections as shown in Figure 8.

While it had been realized for some time that a cross wire on the grids would greatly improve the stability of the grids, no satisfactory brazing method could be devised which would hold the wires in place during the brazing operation. However, the techniques and fixtures which were used in the fabrication of the ribbon screen-grid structures provided the key to a means of brazing cross wires onto the grids without movement during the brazing operation. The fixturing arrangement so devised is shown in Figure 9.

After solving difficulties in: (1) obtaining the proper height for the various elements of the fixturing arrangement, (2) adding the weighted ceramic rod along the center line, and (3) obtaining the correct brazing technique, grids were fabricated containing a successful braze at every cross point in the entire grid.

To preserve the inductive effect provided by the metalizing pattern on the screen-grid ceramic, it was necessary to cut the cross wire every 0.200-inch to eliminate the direct connection from one tube section to the next. (It should be pointed out, however, that the cross wire might be used as an alternate means of providing the necessary amount of screen-grid inductance for regeneration purposes.) The cross wires were cut under a microscope using either a specially prepared ceramic knife or a thin diamond wheel. In subsequent tubes, the cathode coating was also removed between each of the tube sections (Figure 8). The use of cross wires on the control grid has since been incorporated into the control-grid design also, and no difficulties have been experienced with grid wire shorts on these tubes.

5. Other Mechanical Problems

a. Anode Structure

Attempts to utilize a 550°C bakeout temperature on one tube introduced another problem which had occurred to a lesser degree in previous tubes (which had been baked out at 450°C) but which had not been of sufficient magnitude to cause any great concern. In this case, the copper tube body had insufficient mechanical strength to withstand atmospheric pressure at the 550°C bakeout temperature. The result was a dishing-in of the body in the area of the anode structure, causing a closer anode-to-screen grid spacing and hence a considerably higher output capacitance. As a result, the phase velocity of the anode line was

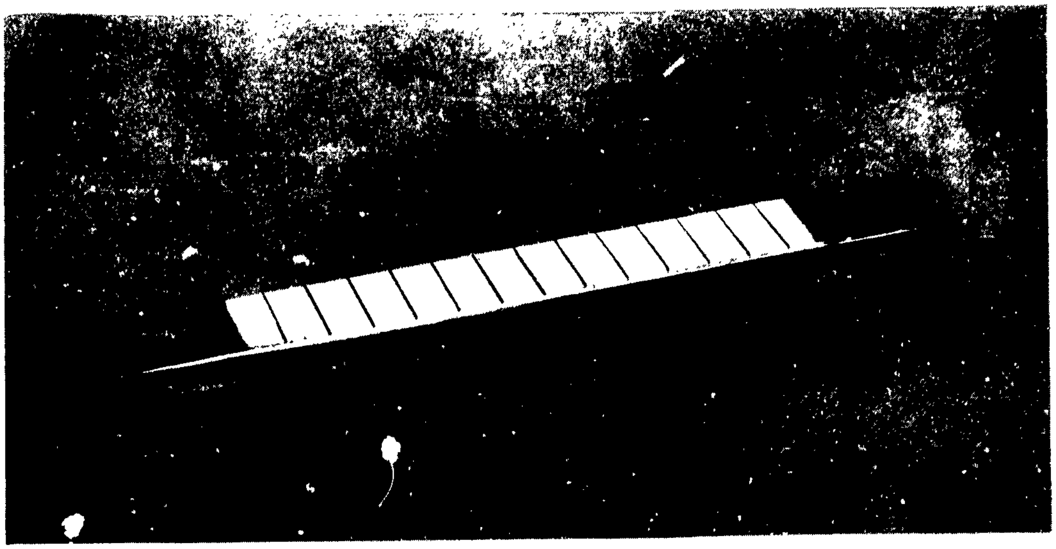


Figure 8 - Over-all View of "Stripped" Cathode

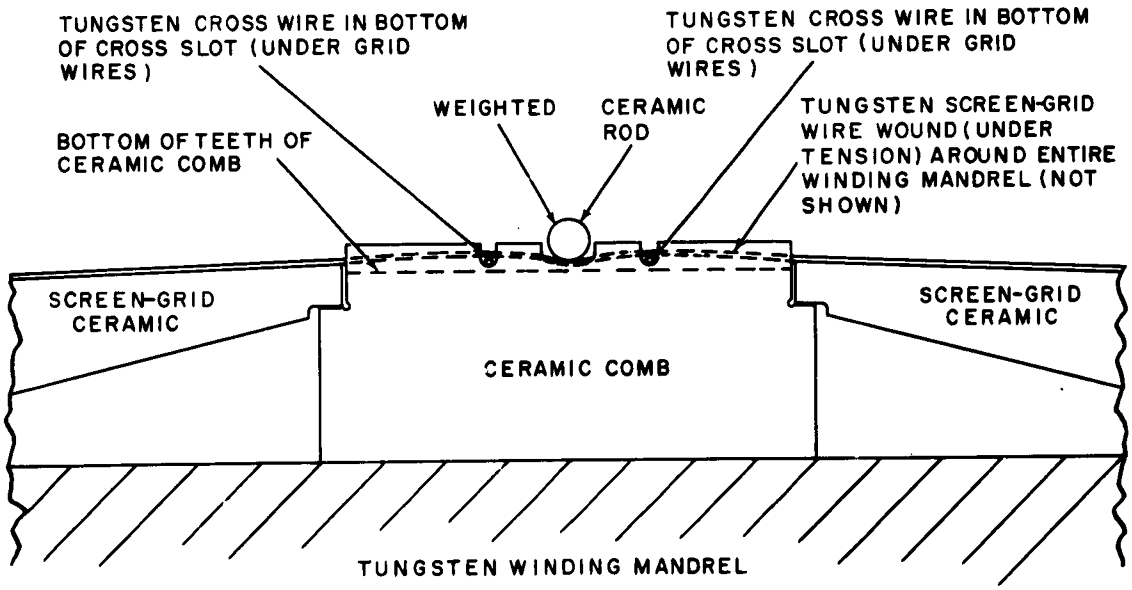


Figure 9 - Schematic Representation of Fixturing Arrangement for Winding and Brazing Cross Wires to Screen-Grid Structure (End View)

different from the grid line. This problem was solved by replacing the copper top and bottom plates of the tube with stainless steel parts and by introducing a stainless steel supporting strut into the radiator assembly.

b. Screen-Grid Bypass

Occasional difficulties were experienced when the screen-grid bypass of the tube shorted. Generally, this occurred only when the control-grid cooling straps had to be handled excessively because the grid package had to be disassembled and then reassembled repeatedly. During this process, the mica would fracture or be mutilated sufficiently to cause fracture and subsequent shorting of the bypass assembly. This problem could be prevented in the fixture by a slight modification of the control-grid ceramic which would protect the mica and prevent any mutilation of the bypass assembly.

c. Films

It was observed that brazing the grid wires (and cross wires) onto the control and screen-grid ceramics left a conductive gold film on the ceramics. While these films did not appear to have caused any difficulty with the rf operation of the device (due to the inherent low rf impedance), they were bothersome from the standpoint of dc screen current leakage. It was found that this leakage can be reduced sufficiently by blasting the ceramics with a fine alumina powder.

PERFORMANCE RESULTS

1. Grid Line Loading

As mentioned previously, one of the major problems which remained from the previous contract (DA 36-039 sc-75070) was that of active rf circuit loading of the grid line. Three major components were contributing to the high-frequency loading of the grid line. These were: (1) cold circuit loading, (2) transit time loading, and (3) active circuit loading. It had been found that the active circuit loading was by far the largest loading factor.[1] Theory, however, predicted that this loading component could be made regenerative as well as degenerative[1] if the input circuit properties were adjusted properly.

Experimental cold circuit measurements of the screen-to-cathode voltage had revealed that a net rf voltage existed between the two electrodes of such a phase, causing the degenerative loading (as the theory predicted) which had been experienced.[3] Additional cold circuit studies of modified circuits revealed the means whereby the phase of the voltage could be reversed by 180 degrees. Such a voltage would make the active loading component regenerative.

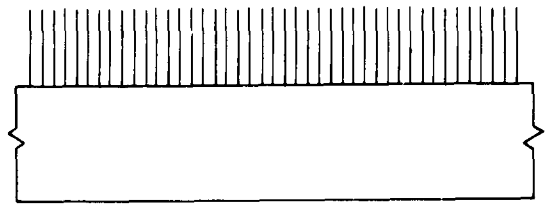
It was found that the 180-degree phase change could be accomplished by simply relocating the grid inductance coil from on top of the control-grid ceramic to the inner surface facing the cathode. The amplitude of the voltage could then be increased, introducing additional inductance into the screen circuit by modifying the screen-grid metalizing pattern, as shown in Figure 10a, 10b, and 10c.

Mechanical difficulties encountered at the end of the previous program had prevented a hot test demonstration of a tube containing one of these modified grid circuits. The results of the cold test data and the theoretical predictions that the active loading could be made regenerative required demonstration. Also the practical limits to which the effect could be utilized to actually compensate for the other degenerative loading effects (i.e., cold circuit plus transit time) had to be determined.

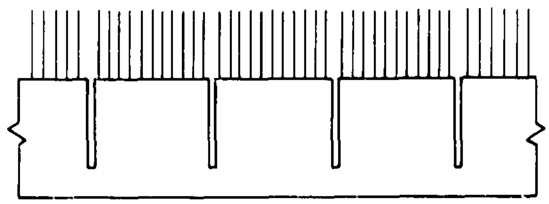
Detailed measurements of the grid line loading components were made on the first rf tube constructed during this program. These measurements demonstrated the feasibility of using active circuit regeneration to compensate for transit time loading even though, for the first time, an oscillation was observed in the device. (See section entitled "Oscillation.")

The circuit which was tested used the screen-grid structure shown in Figure 10b. Figure 11 shows the transit time and active circuit loading over the band from 450 to 650 MC for a screen voltage of 200 volts and a g_m of 65,000 micromhos. (This was for one side of the tube.) It may be observed that the transit time loading is cancelled exactly in the region of 600 MC giving a total net active loss of zero.

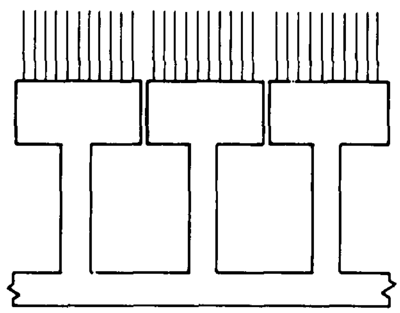
Additional measurements of the total net active loss as well as the cold circuit loss were made on this tube at a somewhat higher value of g_m and lower screen voltage (without bothering to separate components). It should be noted that the cold circuit loss includes the losses caused by mismatch reflections at the tube terminals, which were not



a. Plain Metalizing Pattern



b. Slotted Metalizing Pattern



c. Metalizing Pattern Used to Further Increase Screen-Grid Inductance

Figure 10 - Screen-Grid Metalizing Patterns

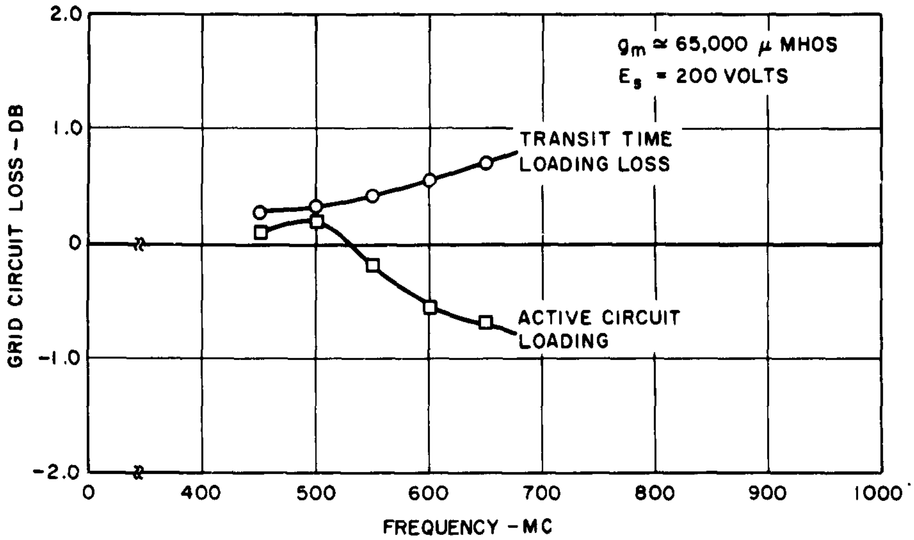


Figure 11 - Active Grid Loading Components versus Frequency

insignificant on this tube. Actual losses would be somewhat lower under perfectly matched conditions. Figure 12 shows the cold circuit loss and the total active loading over the band from 250 MC to 875 MC for a g_m of approximately 150,000 micromhos and a screen voltage of 140 volts. Here again, the compensation for transit time loading around 600 MC is excellent since the total active loading is very small in this region. Above 650 MC, however, the active loading begins to swing positive and negative with rather large gyrations. It is believed that the major cause of these large gyrations is due mainly to the mismatches at each end of the grid line.

An attempt was made on two subsequent tubes to increase the regeneration further in order to compensate for the cold circuit losses in the grid structure. This caused an additional oscillation tendency and a resonance problem around 700 MC. The resonance was believed to be caused by the rf structural properties of the screen structure used (Figure 10c) and resulted in a rather high mismatch at this frequency.

2. Grid Line Matching

a. Input Transformer

In order to match the 30-ohm input circuit to a conventional 50-ohm transmission line over a very wide band of frequencies, so

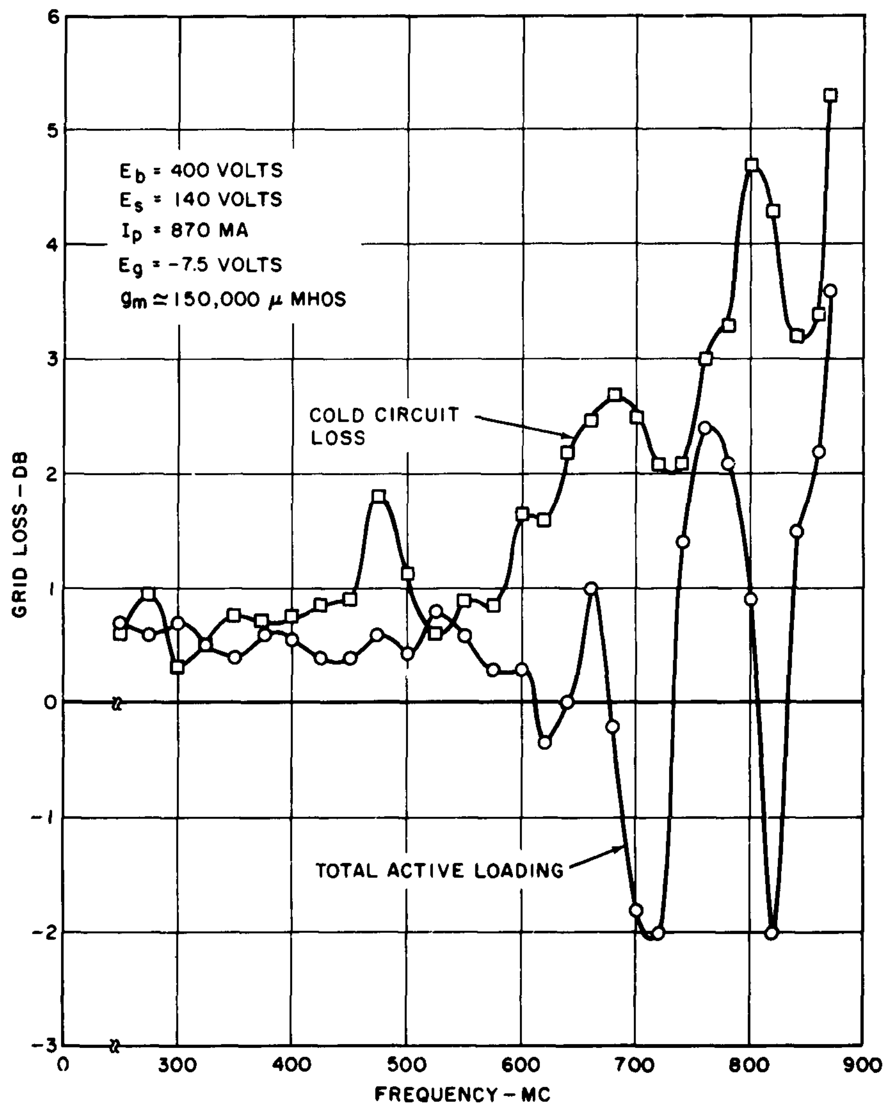


Figure 12 - Grid Loss versus Frequency for One Side of Tube

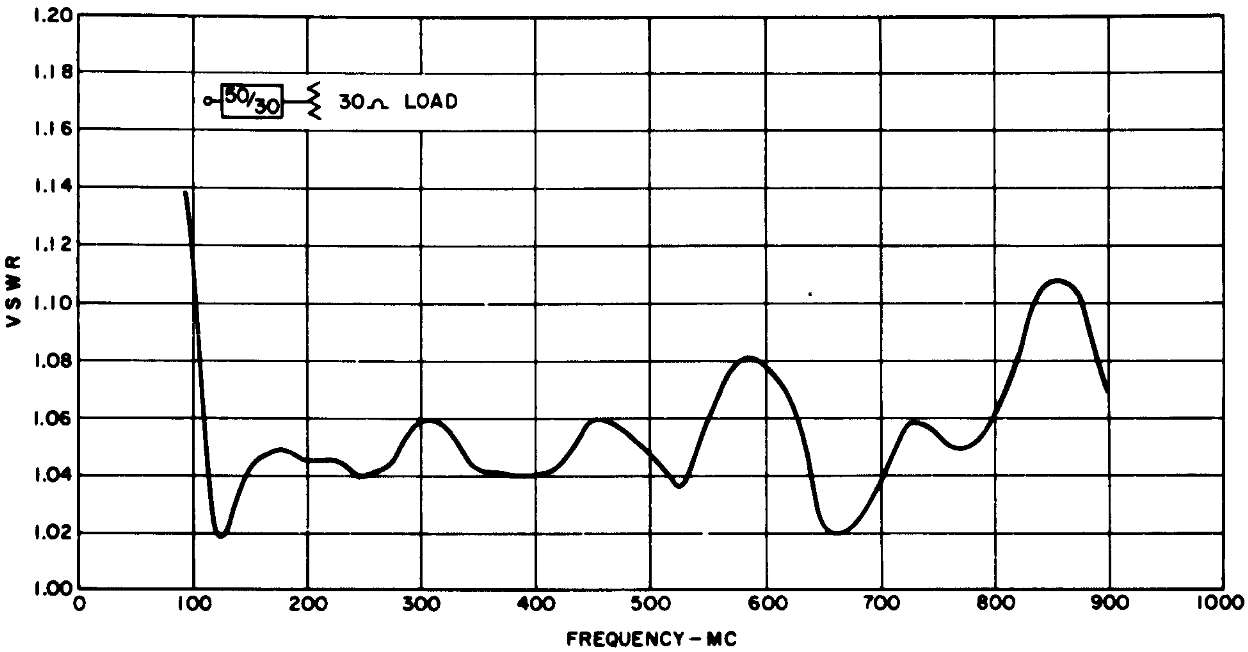


Figure 13 - VSWR versus Frequency for 50/30-Ohm Input Transformer with a 30-Ohm Load

that the various measurements required on the input line could be made with a minimum of effort and also obtain a frequency response with a minimum of ripple, a tapered strip line transformer was constructed utilizing silver foil and 0.010-inch teflon sheet. The VSWR of this transformer was measured using a 30-ohm film-ohm resistor, and the results are shown in Figure 13. It should be noted that the VSWR is below 1.06 over most of the band from 100 MC to 600 MC which was more than adequate for the job.

b. Input Connector Measurements

The transformer just described was utilized to measure the VSWR of the input connectors of the tube when connected to 30 ohms by driving two of the connectors in series with a 30-ohm load from the 30-ohm end of the transformer and measuring VSWR at the 50-ohm end with a PRD impedance meter.

The results of these measurements (Figure 14) showed that the connector design used in the previous contract was not too good,

the VSWR being greater than 1.6 in the 560-MC region. Improvements were made in the connector to improve the match, and the results obtained using the two improved connectors is shown in Figure 15. These data indicate that the new connectors were very nearly 30 ohms as desired.

c. Input Strip Line

Following these tests two sections of strip line, as used in the earlier tubes to connect the input connector to the grid line proper, were inserted in series with the transformer and input connectors as indicated in Figure 16 and the VSWR measured again. A considerable mismatch was observed, caused by the incorrect impedance value of the strip line. The VSWR shown in Figure 17 also shows the effects of the incorrect strip line impedance since this tube (Tube E) contained the improved input connectors.

When the next tube was fabricated, a modification was made in the strip line impedance and an excellent match was obtained, as indicated in Figure 18, with the exception of a single large peak which occurred near 700 MC. This peak was explored further by measuring the grid line attenuation. It was found that a large peak in the grid line attenuation also occurred at this same frequency, as may be seen from Figure 19, indicating a resonant mode in the structure. It is believed that this resonance was caused by the rf properties of the screen-grid structure with increased inductance (Figure 10c) which was used in this tube. Additional evidence to support this belief was obtained when it was found that the screen-grid structure (Figure 20) by itself contained a self resonance of 700 MC. Time did not permit further investigation into ways of eliminating this resonance. It is believed, however, that additional study of the entire input structure, with proper attention to matching the ends of the screen-grid structure, might eliminate the problem.

3. Oscillation

As mentioned previously, as soon as the degenerate input circuit loading was eliminated, an oscillation tendency began to be observed.

Tube B, constructed during this program and containing the screen-grid structure shown in Figure 10b, showed signs of a weak oscillation at 1589 MC (approximate cutoff frequency of grid and plate

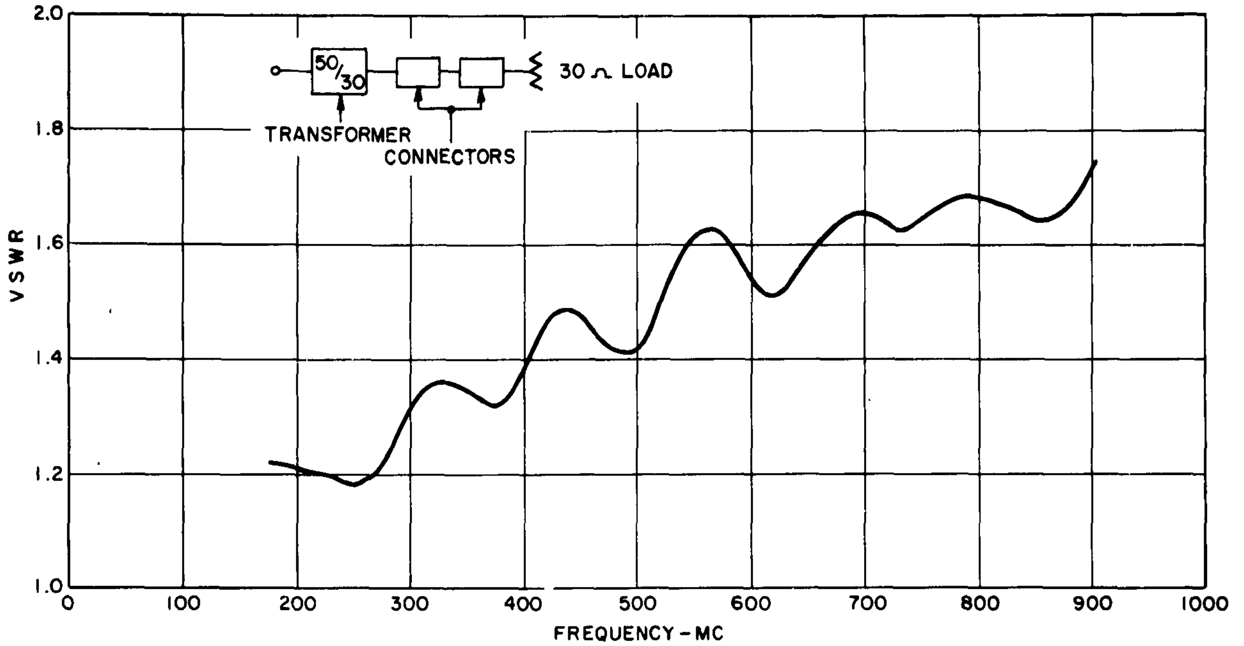


Figure 14 - VSWR versus Frequency for Two Input Connectors in Series with a 50/30-Ohm Input Transformer and a 30-Ohm Load

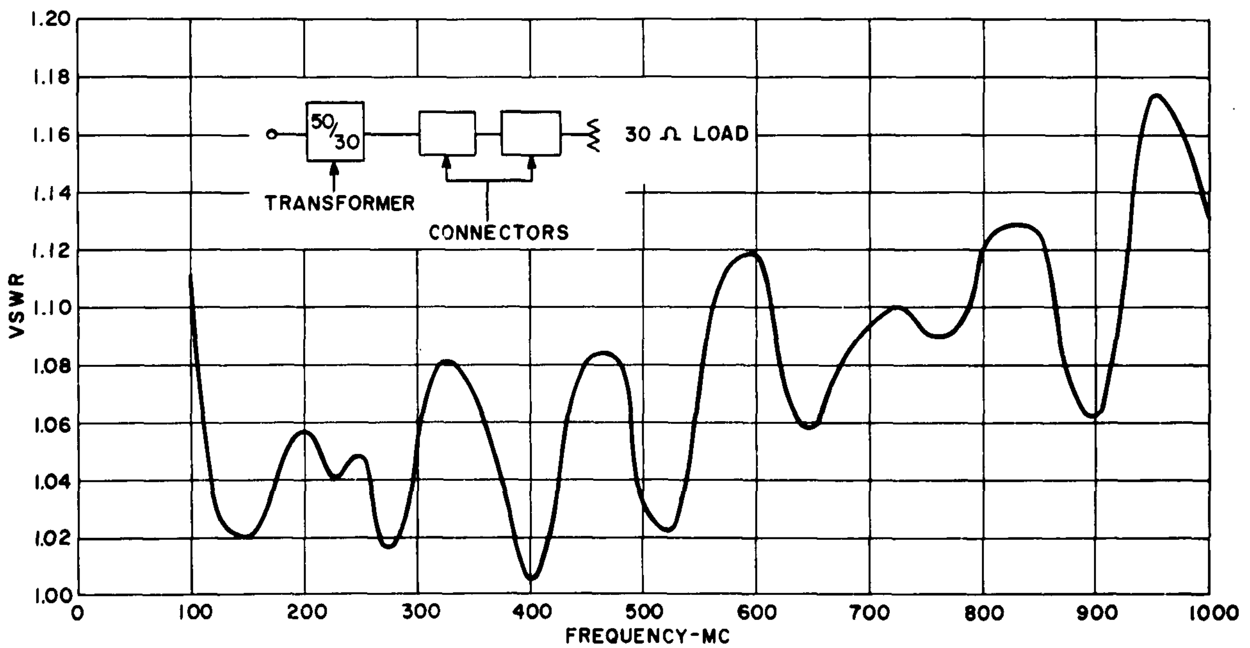


Figure 15 - VSWR versus Frequency for Improved Input Connectors in Series with a 50/30-Ohm Input Transformer and a 30-Ohm Load

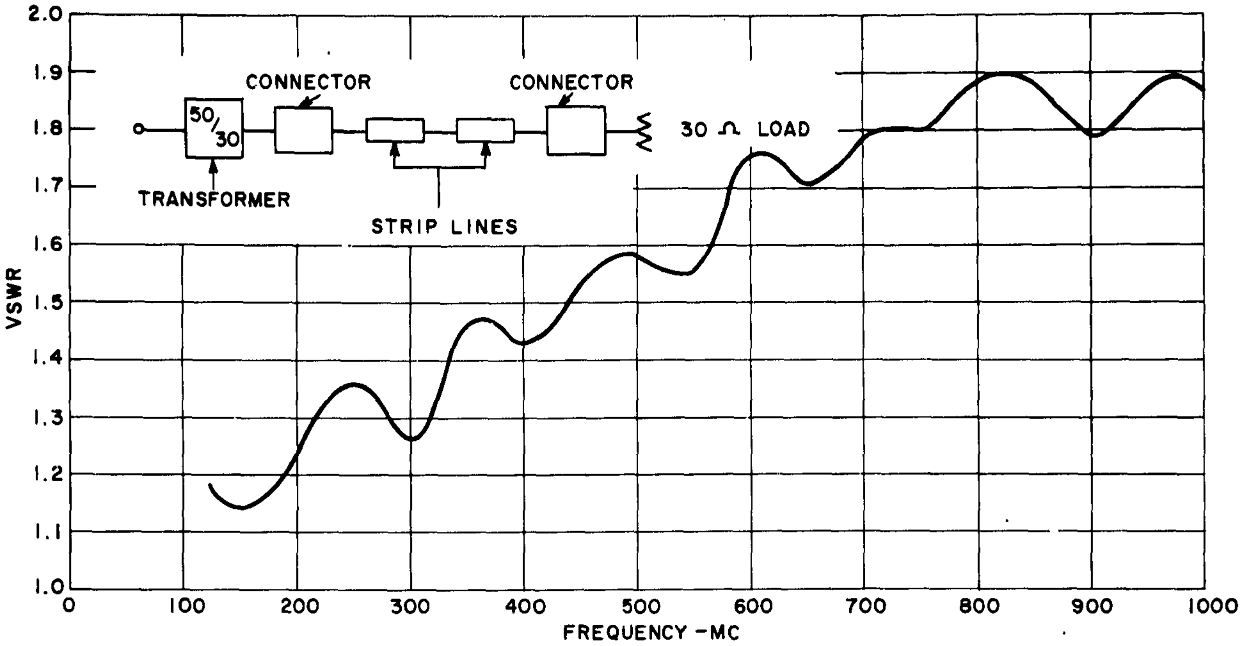


Figure 16 - VSWR versus Frequency for a 50/30-Ohm Input Transformer, Input Connectors, Internal Connecting Strip Lines, and 30-Ohm Load

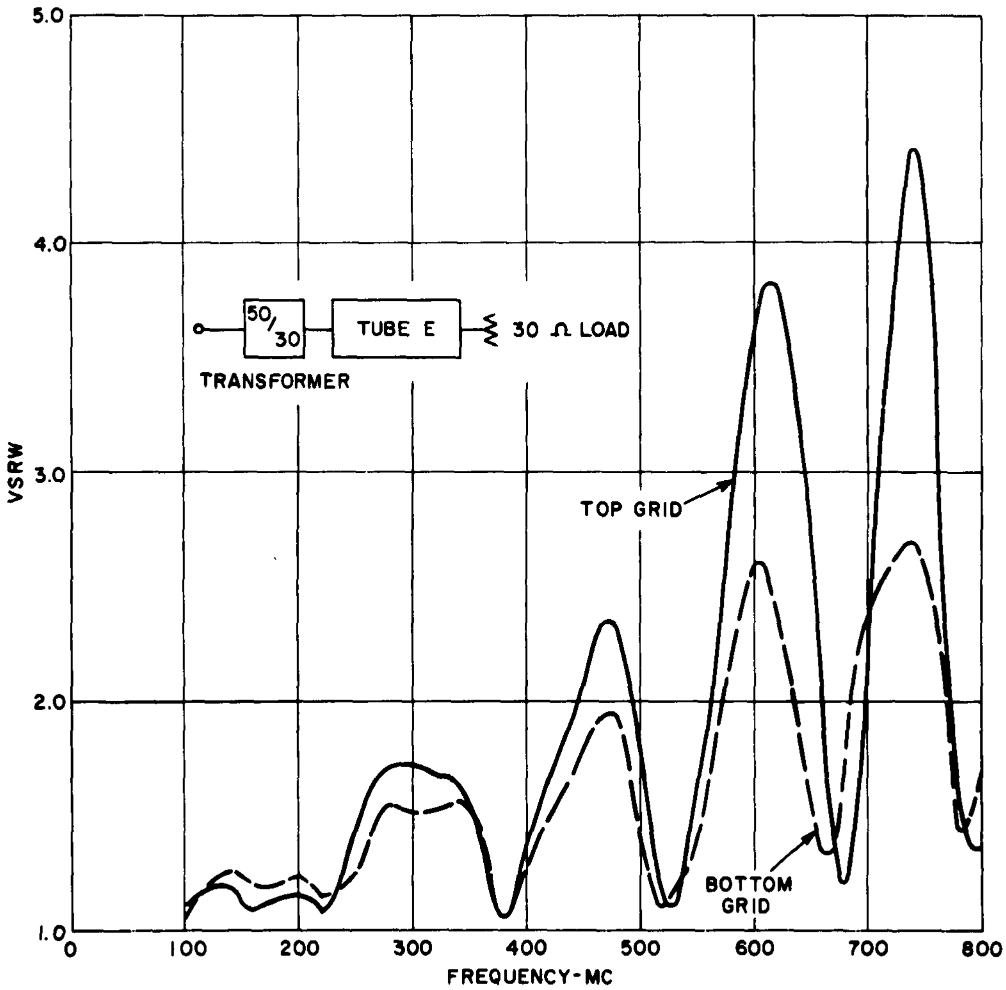


Figure 17 - VSWR versus Frequency for Tube E with a 50/30-Ohm Transformer and a 30-Ohm Load

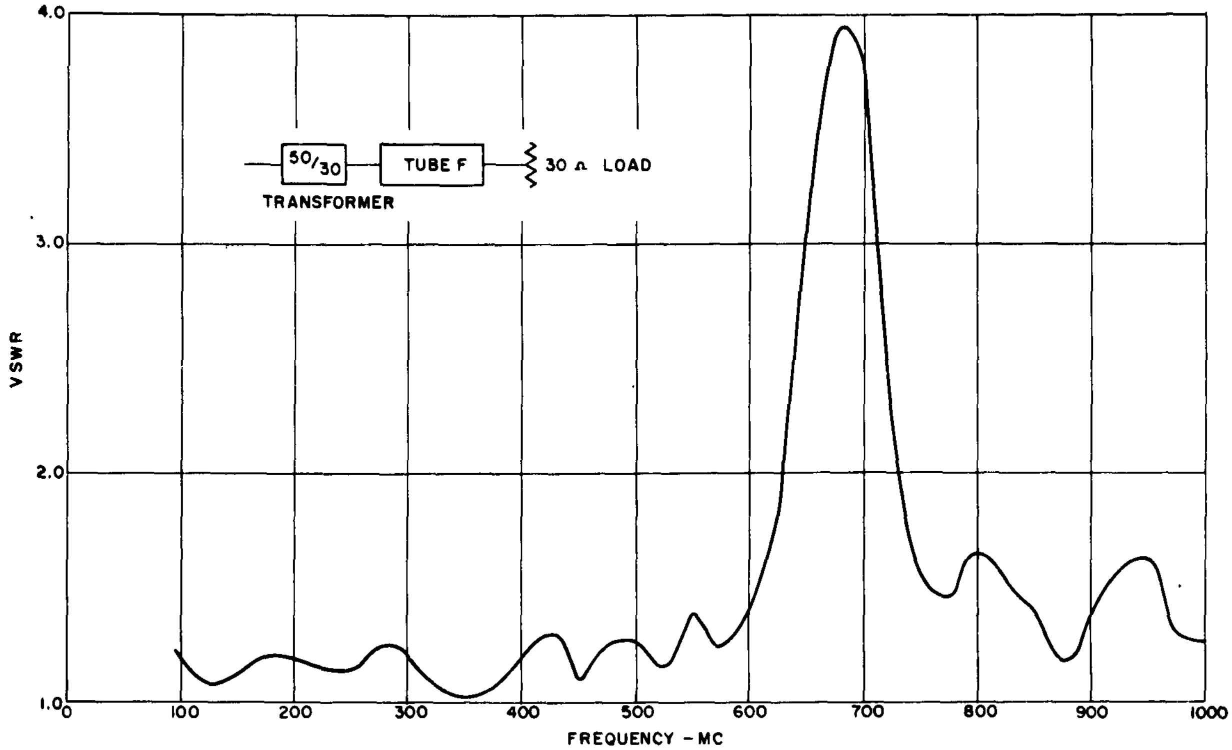


Figure 18 - VSWR versus Frequency for Tube F with a 50/30-Ohm Transformer and a 30-Ohm Load

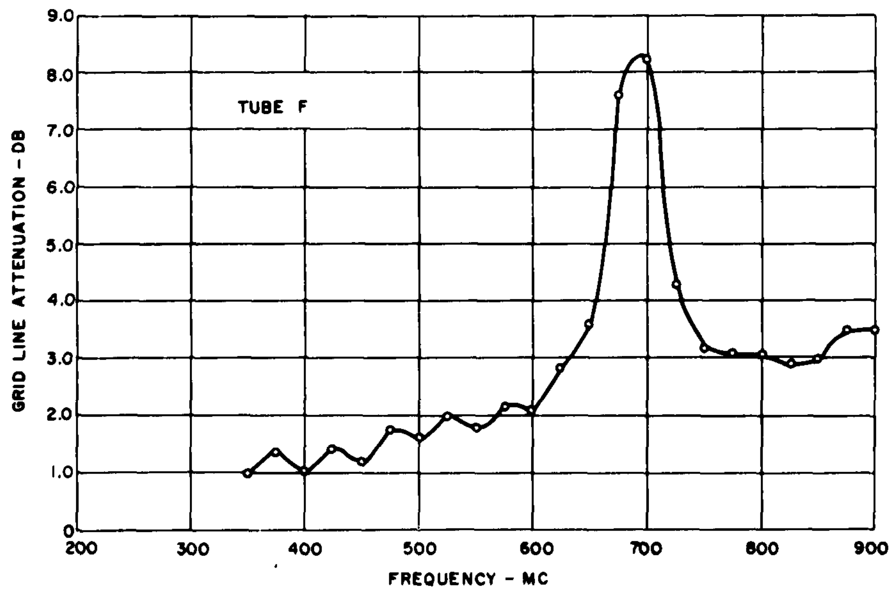


Figure 19 - Grid-Line Attenuation versus Frequency (Bottom Grid Line for Tube F)

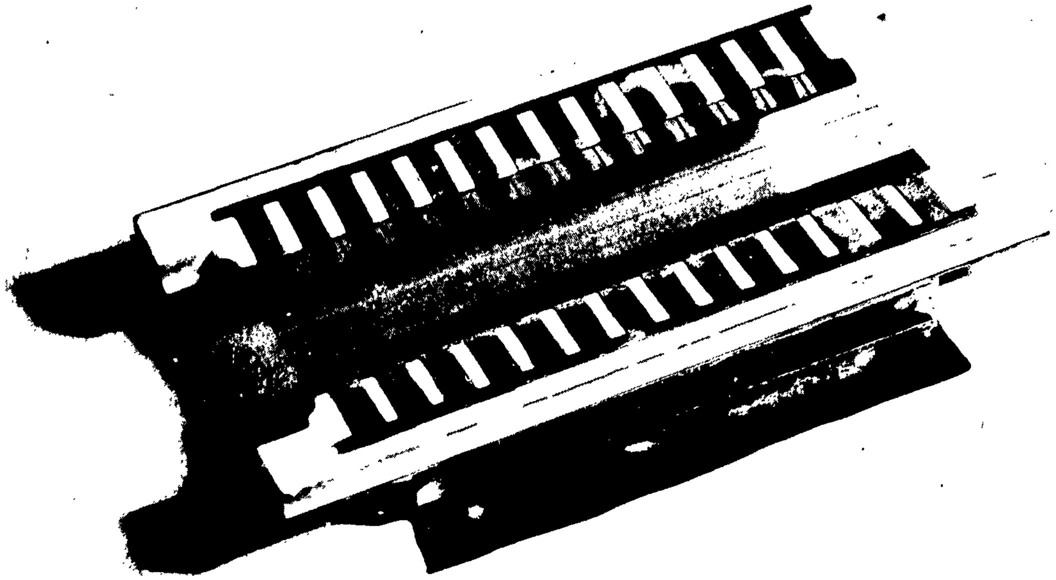


Figure 20 - Over-all View of 120-TPI Screen-Grid Assembly with Two Cross Wires

lines). A detailed study was made of this oscillation during the beginning of this program,[4] and it was concluded that the oscillation was probably caused by the negative loading at sufficiently low screen voltage and by the high circuit impedance near the cutoff of the grid line. Since the oscillation did not occur at normal operating voltage, it did not appear to be of any serious consequence.

No further oscillations were observed until attempts were made to increase the regenerative effect of the screen-grid structure to compensate for cold circuit losses as well as transit time loading. In Tube G, which contained the screen-grid structure illustrated in Figure 10c, it was found that a much stronger oscillation tendency existed. These oscillations interfered considerably in the high-level performance of the device, even though very little power output could be obtained from them. The oscillation was difficult to locate at first, but it was found that several different types of oscillation were occurring. One of these was voltage tunable by either control-grid or screen-grid voltage. There

is some evidence to indicate that the oscillations were due to the waves associated with screen-to-cathode voltage on the input structure which were not terminated. Time and funding did not allow a complete detailed study of these oscillations since they occurred near the end of the contract.

It appeared that the screen-grid structure of Figure 10b would have to be utilized at this time along with the addition of certain improvements in the screen-grid connection so that a greater amount of rf loading to the screen-grid structure could be provided. Tube H contained such a screen-grid structure and improved connection; no oscillations have been observed.

4. Frequency Response

The improvements obtained by the various modifications which reduced grid line losses and improved input matching are illustrated by Figures 21 through 24.

Figure 21 shows the frequency response curve which was obtained during the previous contract on a tube which contained a large degree of degenerative active circuit loading at high frequencies.

Figure 22 illustrates the improved frequency response curve obtained when this degenerative loading was eliminated and made to compensate for the transit time loading. This curve is for Tube B which contained the screen circuits of Figure 10b and on which the data shown in Figures 11 and 12 were obtained.

The data of Figure 23 were obtained on Tube E, which contained the improved input connectors but utilized the same type of screen metalizing pattern as Tube B. The data was taken under somewhat different operating voltages than that of Tube B, however, which accounts for the somewhat higher gain. In general, the curves have about the same slope as would be anticipated.

In an attempt to improve the high-frequency performance further, the regenerative effect of the screen-grid inductance was increased by using the metalizing pattern depicted in Figure 10c. This led to the oscillation difficulties described previously. The data shown in Figure 24 was obtained at a somewhat lower level at which no oscillation occurred. The solid curve shown in Figure 24 is based upon the total forward wave input power at the input to the tube. The dotted curve is

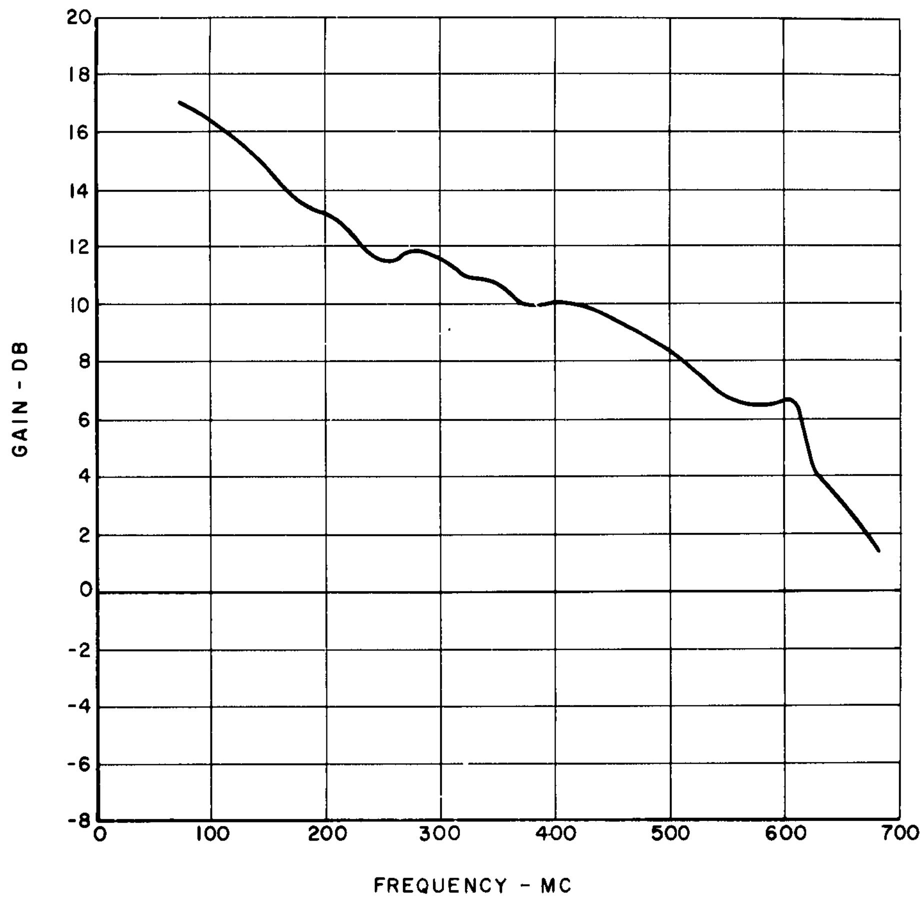


Figure 21 - Gain versus Frequency for One-Half of Tube Obtained during First Distributed Amplifier Contract (DA 36-039 sc-75070)

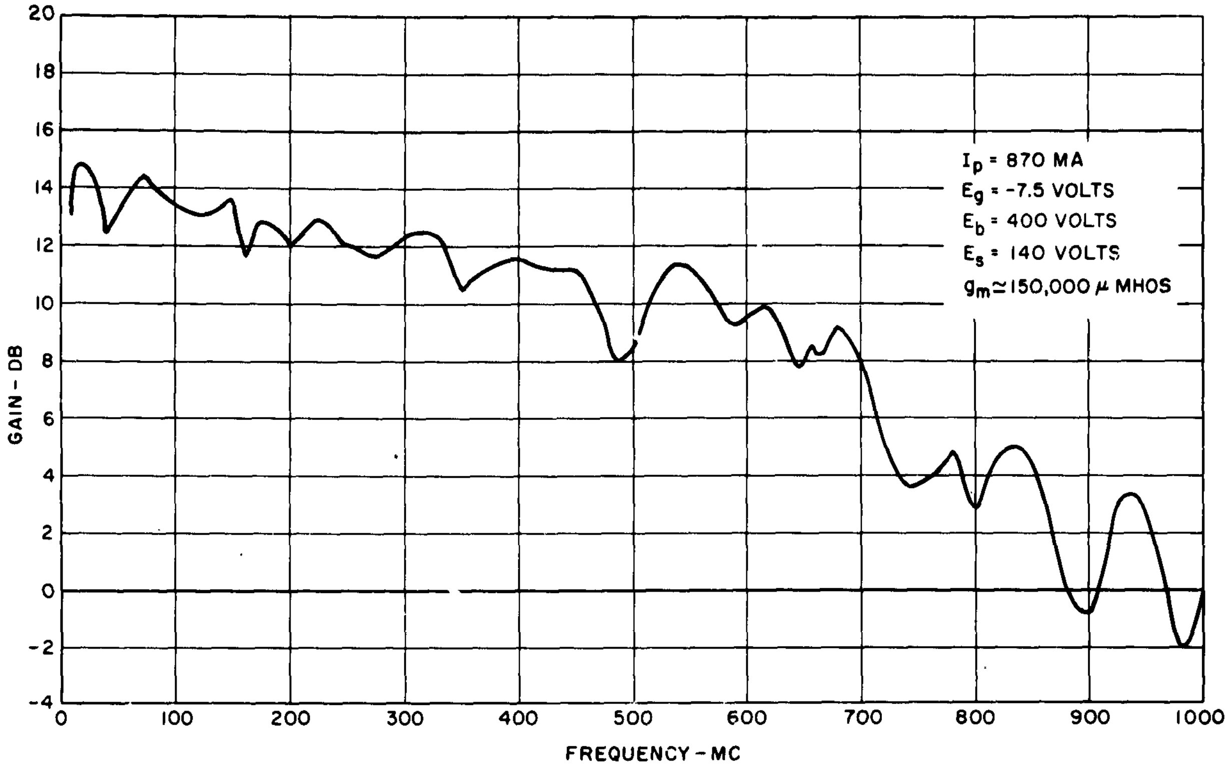


Figure 22 - Small Signal Gain versus Frequency for One Side of Tube B

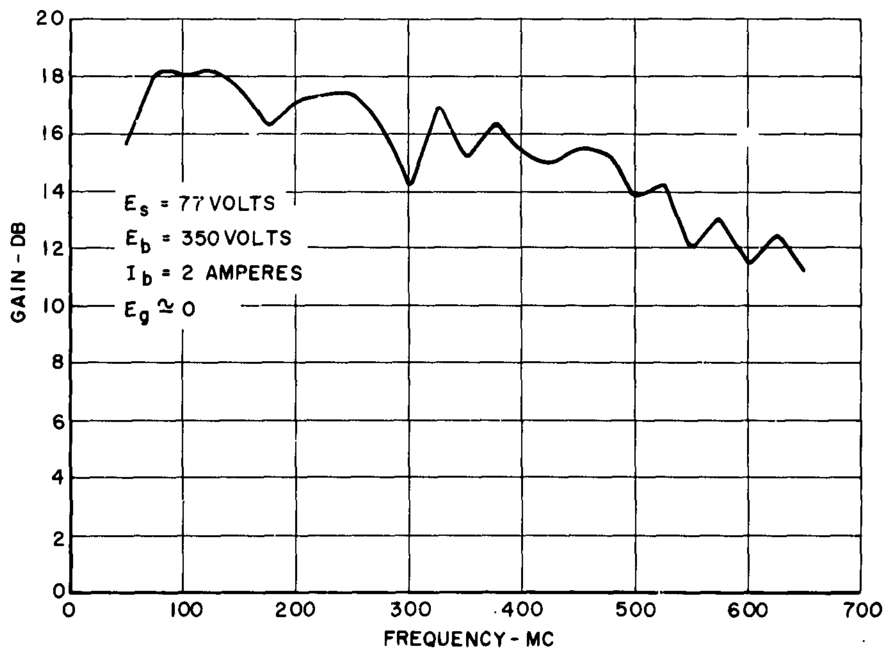


Figure 23 - Small Signal Gain versus Frequency for Top Side of Tube E

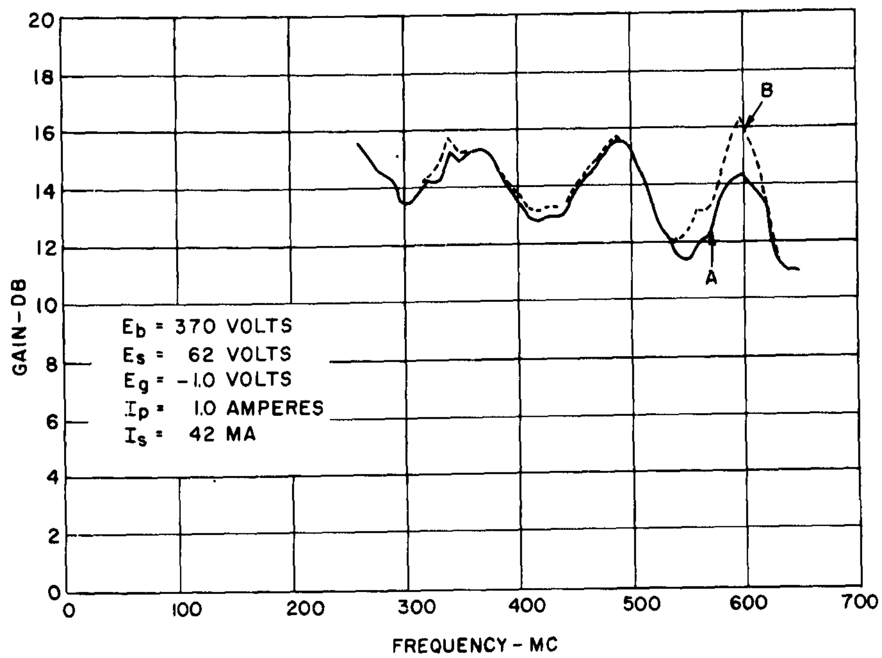


Figure 24 - Small Signal Power Gain for Top Side of Tube F

based upon the forward power minus the reflected wave power at the input to the tube. The actual net drive power to the tube will lie between these two values, since it is not safe to say that all of the reflected power occurs at the input terminal. It may be seen from these data (Figure 24) that the average gain on this tube now is essentially constant over the present band of interest (to 600 MC). The increased degree of excursion about the average value at the high end of the band was due to the somewhat poorer input match on this tube coupled with the increased regenerative effect. The poorer input match was attributed to the change in input impedance caused by an increased input capacitance resulting from somewhat closer spacings used on this tube.

A tube was constructed containing the screen circuit of Figure 10b and including all of the improvements in the input connectors described previously. No small signal gain data were taken on this tube. The high level gain curve which was obtained (see the following section) indicated the frequency response to be quite flat (a variation of approximately two decibels from 300 MC to 600 MC).

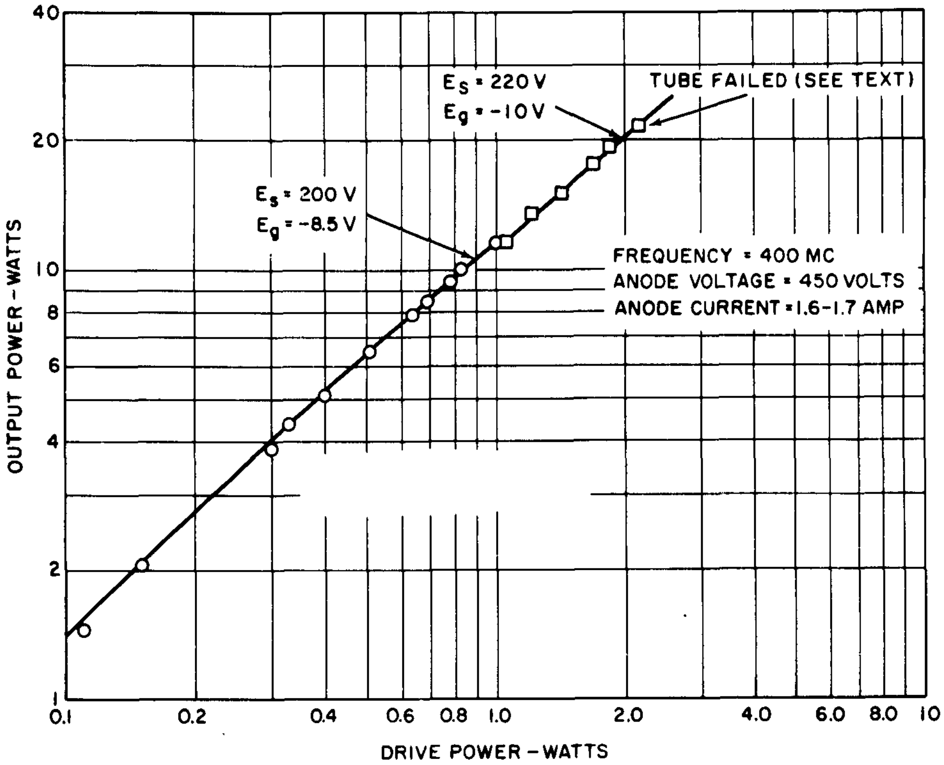


Figure 25 - Power Output versus Drive Power for One Side of Tube B

5. High Level Performance

During the previous contract, as much as 150 watts output was obtained with two watts of drive at 70 MC, but only 24 watts output could be obtained with 3.4 watts of drive at 500 MC. This was due mainly to the large attenuation in the input transmission line caused by the active circuit loading described previously.

Tube B, the first rf tube constructed on this contract, delivered 20 watts of output from one side of the device with two watts of drive at 400 MC (Figure 25) before the tube failed because of a screen-to-anode short when the copper anode straps tore loose and bent down towards the screen grid. The tube also showed signs of excessive screen-grid dissipation on a number of wires, indicating the need for higher screen-grid dissipation capability. Each of these problems was overcome later by the design improvements described previously in the section on mechanical design problems.

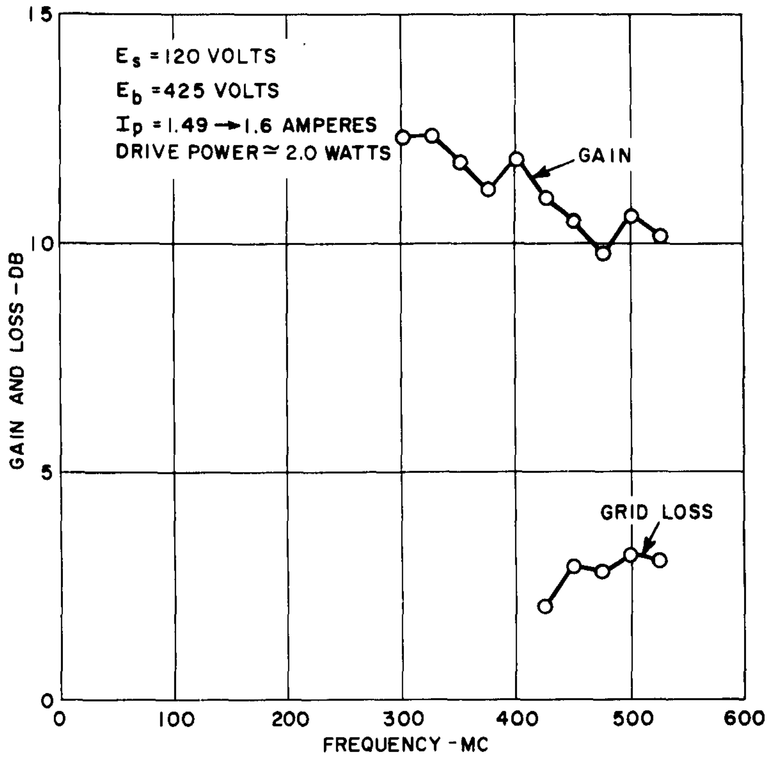


Figure 26 - Large Signal Performance versus Frequency
for Bottom Side of Tube E

Tube E, which utilized the improvements in anode dissipation capability but not the cross wire on the grids, delivered 88 watts of output from one side of the tube with 3.5 watts drive at 300 MC. The large signal gain curve for this same tube is shown in Figure 26. The gain curve was taken after an arc-over occurred in the tube. The arc-over, which caused a considerable loss of emission and gain, was the result of a fault in the anode crowbar circuit.

No large signal data were taken on Tube F (which contained the ribbon screen-grid structure).

On Tube G, which was the tube containing the increased amount of screen-grid regeneration, large signal operation was somewhat erratic because of the oscillation tendency on this tube. Forty watts of output were obtained from one side of the device with five watts of drive at 600 MC. Since the tube would occasionally jump into oscillation, and power output would drop by as much as 40 percent, no detailed large signal frequency response data were taken.

The next tube (H), which contained the screen circuit of Figure 10b and all of the improvements in the input connectors described previously, was operated immediately with both sides of the tube in series and seasoned under rf conditions at 600 MC. After gradually building up the rf drive and plate current by increasing the screen voltage, a power output of 102 watts was obtained at 3.8 watts of drive. By increasing the drive and the screen voltage, power outputs in excess of 120 watts were observed. It was decided to obtain the performance curve as a function of frequency at this level of operation rather than to increase the screen voltage further (to obtain higher gain and power output). This was done and the data shown in Figures 27 and 28 were obtained. During the taking of this data, a very unfortunate thing occurred. After adjusting the output transformer for optimum matching at 475 MC, the reverse termination connection to the anode line became loose and the anode supply voltage which is fed into the tube via the termination began arcing. Before the tube could be shut off, the heat from the arcing cracked the ceramic in the vacuum seal and the tube went down to air. The tube has since been repaired, but no additional data has been obtained.

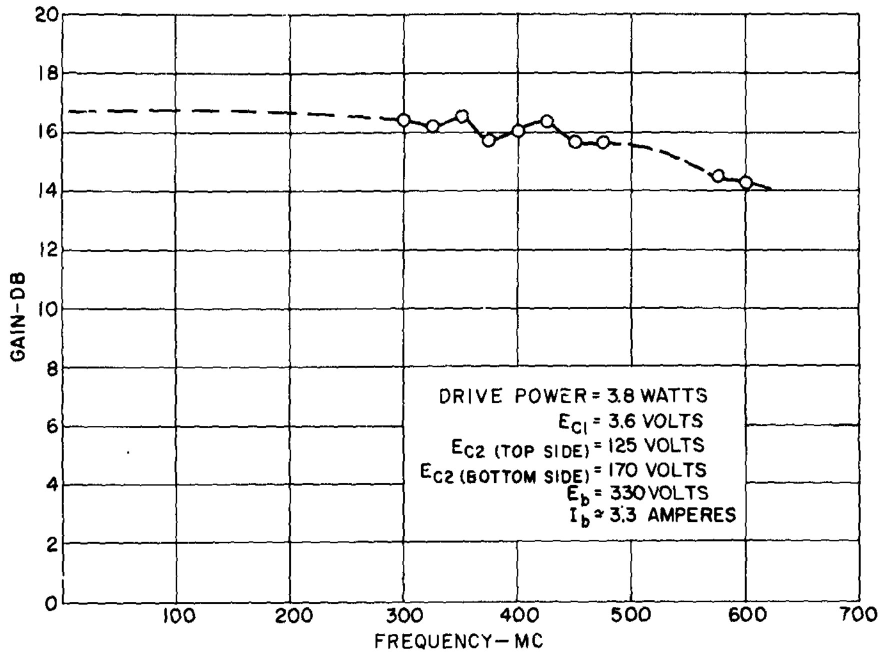


Figure 27 - Large Signal Power Gain versus Frequency for Tube H

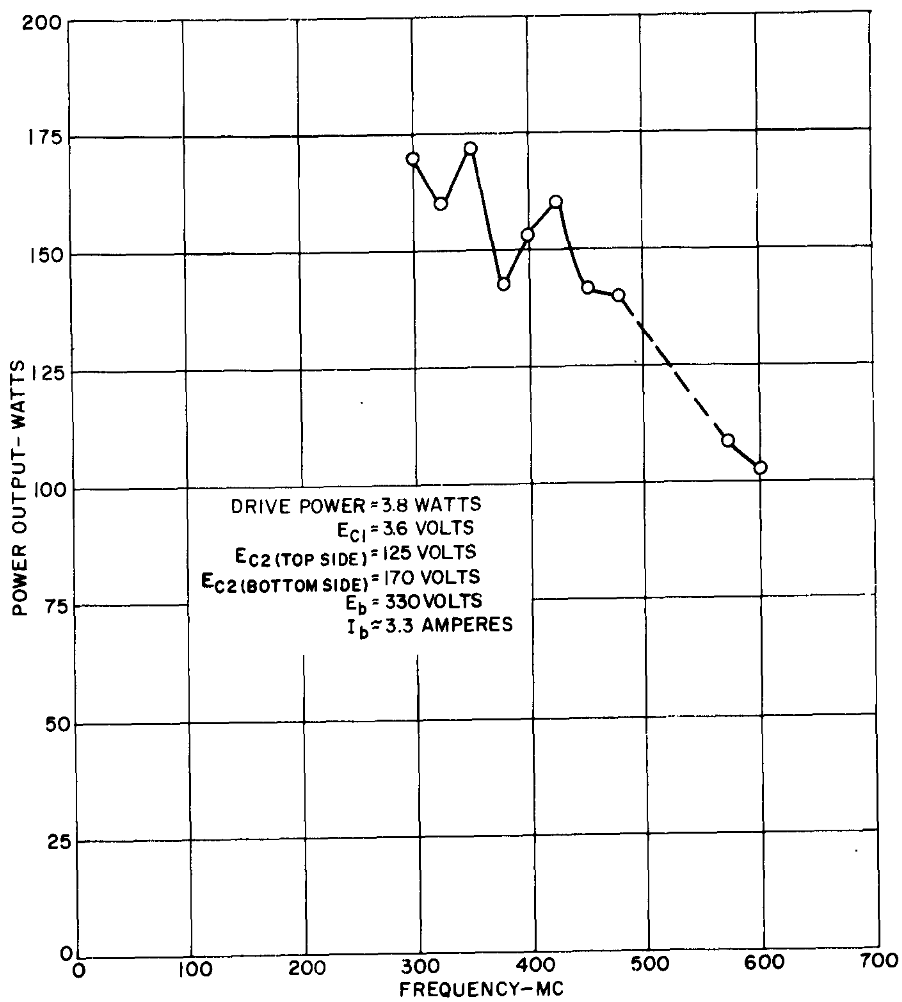


Figure 28 - Power Output versus Frequency for Tube H

CONCLUSIONS

MECHANICAL DESIGN

1. Grid-Shorting Problems

The present design of the grid structure appears to be adequate for present performance level requirements. The grid structure should provide sufficient tension and dissipation capability so that little further difficulty with shorting problems would be anticipated.

2. Anode Dissipation

Anode dissipation capabilities are adequate for present performance level requirements.

3. Cathode-Base Metal System

The present cathode base metal system (20 percent tungsten, 80 percent carbonyl nickel) has proven to be adequate for developmental purposes. However, whether this cathode system will provide the necessary properties required for long life or production processing methods will have to be determined. Such a determination and any required improvements in the cathode base metal system could be conducted during a subsequent Production Engineering Measure program.

4. Grid Design

It has been demonstrated that the final grid design (i. e., round wire with cross wires on both control and screen grid) is adequate for present tube performance levels. No definite conclusions as to the merit of a ribbon type screen-grid structure can be made because the mechanical difficulties mentioned previously (i. e., loose wires) caused an increase in current interception. It was demonstrated that such a grid could be fabricated by machine winding techniques. Additional studies should probably be made to determine the true electrical beaming properties of such a grid in light of its great mechanical robustness.

ELECTRICAL DESIGN

1. Grid Loading and Oscillation

The feasibility of compensating for transit time loading conductance using active circuit regeneration by way of screen-grid inductance has been demonstrated. Increases in regeneration to compensate for cold circuit losses (which may be feasible with further design refinement) led to oscillation difficulties in the present design.

2. Input Matching

Broadband input matching from 50 ohms to the 30-ohm tube input impedance has been demonstrated.

OVER-ALL CONCLUSIONS

The Z-5278 distributed amplifier illustrated in Figure 29 represents a radical departure in the mechanical construction of distributed amplifiers. This distributed amplifier has demonstrated the feasibility of extending this technique to 600 MC with power outputs in excess of 100 watts and a drive power of only 3.8 watts. The basic mechanical design which was developed should provide a basis for making improvements in distributed amplifiers which with additional investigation and newly devised circuit means (see "Conferences" under section entitled "Publications, Lectures, Reports and Conferences") should lead to increased bandwidth or high efficiency and higher power output.

While the performance obtained during this program did not come up to the original contract objectives, the results which were obtained are more than adequate for the specific USAELRDL application for which the development was intended. (See "Conferences.") These same results should make the device applicable to many other applications in this frequency range and power level.

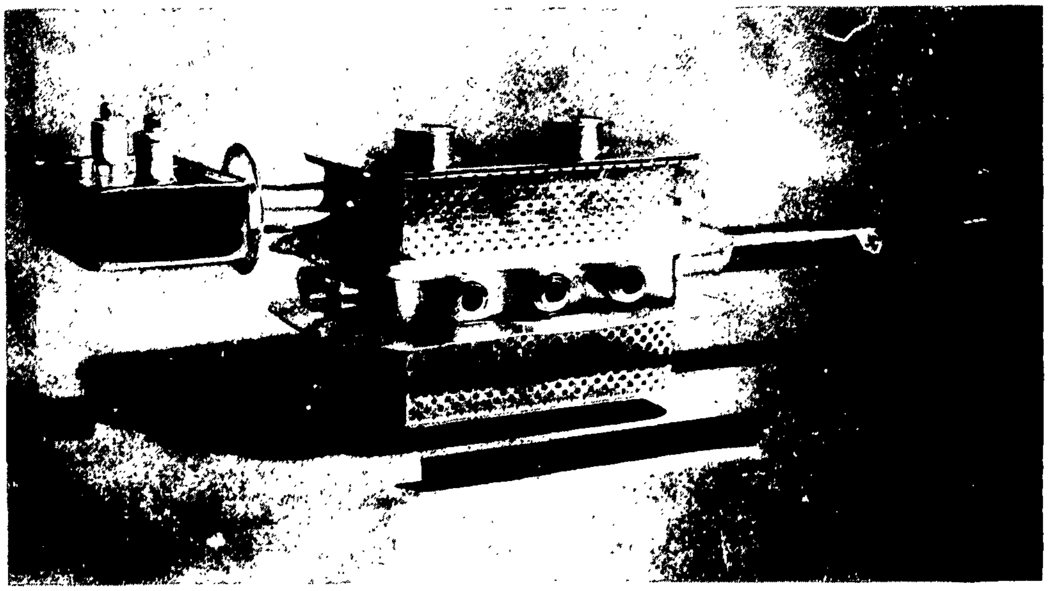


Figure 29 - Over-all View of Z-5278 Distributed Amplifier Developed During This Program

RECOMMENDATIONS

The greatly reduced size and weight of this device, along with the many other advantages attributable to space charge control tubes (i.e., ease of modulation, pulse applications, etc.) should make the Z-5278 distributed amplifier an obvious choice over competing approaches for systems applications in the same frequency range and power level. Therefore, the following recommendations are made.

1. Institute a Production Engineering Measure to study the present design from a manufacturing standpoint and to develop and establish production capability of the device in its present form.

2. Conduct additional studies which will lead to additional improvements in either bandwidth, efficiency, or power output of this type of device.

PERSONNEL

During the period covered by this report approximately 4235 engineering man-hours were devoted to this contract by the personnel listed below. A brief biography of each man is given in Appendix II.

C. B. Mayer	1852 hours
W. J. Rutkowski	2383

Submitted by:

C. B. Mayer

C. B. Mayer, Project Engineer
Transmitting Tube Engineering

Approved by:

R. P. Watson

R. P. Watson, Manager
Transmitting Tube Engineering
Power Tube Department

September 12, 1963

APPENDIX I - REFERENCES

1. Report No. 12, "Tubes for Use in a 25-Watt Distributed Amplifier," 1 July 1961 through 30 September 1961. Contract No. DA 36-039 sc-75070. Power Tube Department, General Electric Company. 1961.

2. Report No. 14, "Tubes for Use in a 25-Watt Distributed Amplifier," 1 January 1962 through 31 March 1962. Contract No. DA 36-039 sc-75070. Power Tube Department, General Electric Company. 1962.

3. Report No. 13, "Tubes for Use in a 25-Watt Distributed Amplifier," 1 October 1961 through 31 December 1961. Contract No. DA 36-039 sc-75070. Power Tube Department, General Electric Company. 1962.

4. Report No. 15, "Distributed Amplifier Tubes," 1 May 1962 through 31 July 1962. Contract No. DA 36-039 sc-90743. Power Tube Department, General Electric Company. 1962.

APPENDIX II - BIOGRAPHIES

Charles B. Mayer
Development Engineer - Distributed Amplifier Tubes

Mr. Mayer joined the General Electric Company after graduation from the City College of New York in 1951 where he received his BEE degree and had done some graduate work in high-frequency techniques and servomechanisms. During his first year with the Company he was a member of the Engineering Training Program and worked on fire control systems, microwave duplexer project, and transistor circuit design.

Late in 1952 Mr. Mayer was selected for the Company's three-year Advanced Engineering Program. During this time, assignments included work in the following areas: transistor research, magnetron starting characteristics, traveling wave tube research, advanced systems development, crystal controlled oscillator stability, and self-diplexing transmitting system for which latter work he has been issued a patent.

In 1955 he transferred to the Power Tube Department and was assigned to the General Electric Research Laboratory where he worked on long pulse emission properties of oxide coated cathodes and high-temperature circuits. From 1956 to 1959 he was engaged in research in connection with the principles of extended interaction and was instrumental in the development of the L-139 extended interaction tetrode.

Mr. Mayer joined the staff assigned to the distributed amplifier program (Contract No. DA 36-039 sc-75070) at its inception in May 1958. to work on the development of the single tube distributed amplifier. He has been project leader of the entire project on both Contract No. DA 36-039 sc-75070 and No. DA 36-039 sc-90743 since December 1958.

Mr. Mayer has been a senior member of the Institute of Radio Engineers since 1955 and is a member of the Professional Groups on Electron Devices, and Microwave Theory and Techniques and served as the Chairman of the Schenectady Chapter of the Microwave Theory and Techniques Group for 1962-1963.

Walter J. Rutkowski
Development Engineer - Transmitting Tubes

Walter J. Rutkowski graduated from Siena College in 1951 with a B.S. degree in Mathematics. Following graduation, he joined the Industrial Control Laboratory of General Electric Company, transferring to the Power Tube Department in 1952.

Mr. Rutkowski presently serves as Development Engineer - Transmitting Tubes in the Transmitting Tube Engineering Subsection. In this capacity, he is concerned with advanced development work on the Z-5278 Distributed Amplifier, including the establishing of new assembly and processing techniques. Mr. Rutkowski has been assigned to the distributed amplifier program (Contract No. DA 36-039 sc-75070 and No. DA 36-039 sc-90743) since the beginning of 1960.

AD

Power Tube Dept., General Electric Co., Schenectady, N. Y. DISTRIBUTED AMPLIFIER TUBES by C. B. Mayer. Report No. 19, final report, 1 May 62 - 31 July 63. 48 p. incl. illus. (Contract DA 36-039 sc-90743, continuation of Contract DA 36-039 sc-75070) Unclassified Report

This report describes the continuation of the research work conducted under Contract No. DA 36-039 sc-75070 on a single-tube distributed amplifier. The problems encountered and the solutions obtained which have led to the present performance are described. The major improvements which have been made in the tube are: (1) increased anode dissipation capability, (2) increased screen-grid dissipation capability and stability, and (3) improved emission. These improvements, together with circuitry studies and modifications, have led to improvements in frequency bandwidth, power output, and power gain. The best performance which has been obtained to date is discussed. The ultimate performance of the present design has not been determined.

UNCLASSIFIED

1. Electron tubes
2. Tubes - Distributed amplifier

I. Title: Distributed amplifier
II. Mayer, C. B.
III. U.S. Army Electronics R&D Lab.
IV. Contract DA 36-039 sc-90743

AD

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This report describes the continuation of the research work conducted under Contract No. DA 36-039 sc-75070 on a single-tube distributed amplifier. The problems encountered and the solutions obtained which have led to the present performance are described. The major improvements which have been made in the tube are: (1) increased anode dissipation capability, (2) increased screen-grid dissipation capability and stability, and (3) improved emission. These improvements, together with circuitry studies and modifications, have led to improvements in frequency bandwidth, power output, and power gain. The best performance which has been obtained to date is discussed. The ultimate performance of the present design has not been determined.

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This contract is supervised by the Special Tubes Branch, Electron Tubes Division, Electronic Components Department, USAELRDL, Fort Monmouth, New Jersey 07703. For further technical information contact:

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